HORTICULTURAL AND ENVIRONMENTAL ASPECTS OF WEED CONTROL IN FLORIDA CITRUS

By

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This dissertation is dedicated to my family, friends, and colleagues without whose support and encouragement it would not have been completed.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

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Florida citrus growers must combine horticultural and ecological considerations to produce citrus in an environmentally friendly and economically viable manner while controlling weeds and production costs. Studies were conducted over a two-year period using seven preemergence herbicides to assess their safety toward citrus seedlings, herbicide mobility in soil and, in field studies, the herbicide's effectiveness for controlling weeds and the effect that weed control had on the growth of young citrus trees. Herbicides evaluated were bromacil, diuron, norflurazon, oryzalin, oxyfluorfen, simazine, and thiazopyr.

High rates of herbicides, especially bromacil, can reduce shoot and root growth of citrus seedlings. If only mild phytoxicity symptoms appear on seedlings and additional

applications at damaging rates are not applied, the seedlings should not suffer long-term damage. Differences between Carrizo and Swingle were noted in their tolerances to herbicide applications with Carrizo being more sensitive to herbicide application than was Swingle.

The seven herbicides were studied under various simulated rainfall rates. The herbicides can be divided into low, moderate, or high soil mobility based upon their movement in the soil column studies. Low mobility herbicides were oryzalin, thiazopyr, oxyfluorfen, and diuron. Moderately mobile herbicides were norflurazon and simazine. The highly mobile herbicide was bromacil. Bromacil moved to a greater depth than all other herbicides at various simulated rainfall rates.

Field studies indicated all preemergence herbicide treatments provided significantly greater weed control that was true for controls. Treatment rankings based on overall mean weed control showed that treatments that included norflurazon or bromacil provided the highest level of control. Weed control was generally highest in the Ridge citrus production region (Lake Garfield) and poorest in the Flatwoods growing region (Arcadia), with intermediate control in the Indian River region (Indiantown). Seasonal variations in weed control were observed with frequency and time of herbicide application.

Weeds compete with the citrus trees for moisture, nutrients, and light. Where weed competition is reduced or inputs are not limiting, tree growth is not significantly affected by weed growth.

CHAPTER 1
INTRODUCTION

It is generally accepted that a weed is a plant growing where it is not wanted. The management of weeds in Florida's citrus groves has been a focus of discussion and study dating back to the early meetings of the Florida State Horticultural Society in 1892 (FSAS, 1892) when weeds were occasionally cut with a brush scythe. Even as early as 1886, discussion centered around how to cultivate citrus groves to remove unwanted vegetation. At that time, it was mentioned that much is yet to be learned about the citrus fruit and that time and experience are still required (Harcourt, 1886), which is still true today, some 110 years later. In the early 1900s farmers in the United States were encouraged to collect specific weed parts as a source of crude drugs to supplement their income (Henkel, 1904). Some of these weed species were commonly found in Florida.

The early attempts at citrus weed management dealt mainly with mechanical control of weeds by mule- or horse-drawn plows or cultivators and by hand hoeing. Today, due to the scarce supply of labor and its cost, the citrus industry relies very heavily on the use of chemicals that have herbicidal properties. Herbicides can provide weed control not only under the tree canopy but within the row middle, depending on the selected herbicide material and its placement and rate. Herbicidal oils have been used for a number of years, but the early trials in Florida showed limited success (Reitz & Long,

1953, 1954). It was not until 1956 that controlled experiments were conducted in commercial citrus acreage using herbicides on annuals and perennial grasses (Burt & McCown, 1959). These studies were the beginning of preemergence weed control that allowed the Florida citrus grower to efficiently and economically control the vegetation around the trees, shifting from mechanical and hand hoeing to chemical weed control. While limited grower trials were begun in 1962, it was not until 1964 that extensive grower use of herbicides began (Ryan, 1969).

Weeds compete with citrus trees for nutrients, moisture, light and space, and harbor insects and rodents that attack citrus trees. Weeds also affect harvesting operations, water distribution patterns from irrigation systems emitters, disease control, and environmental conditions within the grove. The combination of chemical, biological (Burnett et al., 1973), mechanical, preventive, and, to a lesser extent, hand labor methods are used today to provide effective and economical weed management in Florida citrus groves.

This dissertation will examine (1) the history of weed control practices in Florida citrus, (2) the effect of specific preemergence herbicides on the growth of citrus and live oak seedlings, (3) herbicide mobility in soil columns, and (4) field studies that investigate the effectiveness of these chemicals to control vegetation (weeds) under the tree and the subsequent tree growth during a two-year field study. Throughout this study seven herbicides have been thoroughly examined. They are bromacil (Hyvar 80WP), diuron (Direx 80DF), norflurazon (Solicam 80DF), oryzalin (Surflan 80DF), oxyfluorfen (Goal 1.6E), simazine (Princep-Caliber 90DF), and thiazopyr (Mandate 2E). These herbicides

(with the exception of thiazopyr which obtained registration in 1997 and oxyfluorfen) are the preemergence herbicides which were recommended in the University of Florida publications for the use in Florida citrus at the time this work was conducted.

CHAPTER 2
WEED CONTROL PROGRAMS IN FLORIDA CITRUS

Today, citrus is one of the most important agricultural crops in the Florida economy, comprising 857,687 acres (Florida Agricultural Statistics Service, 1996a) with an on tree value of $1.1 billion for the 1995-96 crop year (Florida Agricultural Statistics Service, 1996b). Local television news reports in August 1997 estimate the economic value of Florida citrus to the state's economy at $8 billion with 144,000 people employed in the industry.

Control of weeds has always been a major economic cost in citrus production because Florida's very favorable climate allows for weed germination and year-round growth. Weeds compete with citrus trees for nutrients, light, water, and space. Additionally, weeds can increase fire hazards within groves, increase cold damage from radiation freezes (Tucker et al., 1980), increase the incidence of *Phytophthora* foot rot, impede harvesting of citrus crops, interfere with low volume irrigation systems, and intercept soil-applied chemicals, thereby reducing their effectiveness. In 1991, the estimated annual average monetary loss caused by weeds in Florida's 507,730 acres of citrus was $73.7 million, which would have reached $442.4 million if no herbicides had been used (Bridges, 1992). Extrapolating forward with today's increased acreage, weed loss cost could exceed $124.5 million in 1997 and would reach $747.3 million if no

herbicide were being used. Desirable vegetation species in the row middle, however, can minimize soil erosion from both wind and water and provide nutrients and organic matter to the soil. Thus, the objective of today's citrus weed management program is not the elimination of all weed species from the grove floor but rather to suppress the undesirable effects of weed populations to a level that economic losses do not exceed the cost of weed management programs.

Cost of Weed Control in Florida Citrus

The use of chemical weed control has increased dramatically due to labor costs, equipment costs, product costs and availability, the shift to more narrowly spaced tree rows, and installation of low volume irrigation systems that prohibit the operation of mowing or tillage equipment under the tree canopy area. Weed control for the crop year 1995-96 accounted for 24.44% of the annual total specified production costs or $204.75 per acre in Central Florida citrus (Muraro & Oswalt, 1996). Cost for the other citrus regions within the state will vary slightly from the Central Florida production region. Using the Central Florida region cost data and assuming that 90% of the state's citrus has some type of chemical weed control under the tree, the total cost of herbicide materials and application equals $97.7 million per year. In addition to the cost of managing weeds under the tree, management of vegetation and/or weeds in the row middle is $48.6 million, bringing the total annual weed management costs to the Florida's citrus industry to $146.3 million.

Over the past 20 plus years, the University of Florida has issued annual reports listing the estimated annual per-acre costs and returns for a mature Valencia grove producing fruit for the processed market. From these, selected reports at five-year intervals were chosen to provide the following estimates of the cost of weed management programs (under tree and row middles): $31.25 in 1976-77 (Muraro & Abbitt, 1977), $46.44 in 1980-81 (Muraro, 1981), $91.93 in 1985-86 (Muraro, 1986), $153.44 in 1990-91 (Muraro et al., 1991), and $204.75 in 1995-96 (Muraro & Oswalt, 1996). Thus, the weed control cost, as a percentage of the total specified cost, has increased from 9.03% in 1976-77 to 24.44% in 1995-96 with the total annual cost of production increasing from $346.19 to $837.70, respectively (Table 2-1).

Table 2-1. Estimated cost for herbicide program and total specified cost of production per acre for a Valencia grove producing fruit for the processed market in Central Florida area.

Production Year	Annual Weed Management Costs	Annual Specified Production Costs	Weed Control as a Percent of Total Specified Costs
1976-77	$ 31.25	$346.19	9.03
1980-81	$ 46.44	$539.53	8.61
1985-86	$ 91.93	$618.08	14.87
1990-91	$153.44	$892.16	17.20
1995-96	$204.75	$837.70	24.44

Benefits from Herbicides

Regardless of the cost of labor, herbicide use provides benefits from both an economic and a grove floor management standpoint. By using herbicides, the need for hand labor is minimized and in some cases can be almost eliminated. The application of preemergence soil-applied herbicides can prevent seed germination, thus eliminating early weed growth and competition with the citrus tree and improving efficiency of nutritional and pesticide application. Equipment costs and operational costs are generally reduced compared to those for mechanical, tillage, or mowing operations. Movement within the grove is improved for cultural and harvesting operations. Proper herbicide applications can minimize injury to citrus tree trunks and roots compared to mechanical hoeing, tillage, or cultivation operations. Injured tree trunks and roots are more susceptible to attack and injury by soil-borne pest and diseases (Jordan et al., 1992). Properly timed herbicide applications can reduce the number of seeds in the soil (seed bank) that are available for germination. The combination of herbicides and noncompetitive cover crops can reduce soil erosion compared to tillage operations, which is especially important in the bedded grove systems.

Citrus Tree Response to Herbicides

Herbicides that are properly selected and applied for specific tree age, scion, and soil type will not significantly injure otherwise healthy citrus trees. Citrus tree damage has been noted to occur when (1) an incorrect dosage was applied, (2) materials have been

applied to the foliage of the tree, (3) trees were too young for use of a specific herbicide, (4) the material was applied to very sandy soils, and (5) the trees were adversely affected by cold, flooding, or other stress factors. Herbicide damage to foliage and fruit has also been noted when herbicides were applied under windy conditions or use of improper equipment allowed the materials to contact areas other than the weeds or soil.

Positive tree responses have also been noted in groves that were properly treated with herbicides compared with those that were not treated or those that were cultivated. The canopy volume and tree trunks are larger in herbicide-treated groves, which will allow for increased production of citrus fruits (Jordan et al., 1992). This increase in size is due to the reduced competition of weeds for light, water, space, and nutrients along with the reduced injury to the tree from cultivation damage to the roots or tree trunk from hand or mechanical hoeing (Jordan, 1978, Singh & Tucker, 1984). The extent of the above competitions will vary with each grove and in some cases even within a given grove due to soil type and weed pressure.

Effect on the Grove Environment

Weeds will influence the grove environment by affecting both soil and air temperature and providing organic matter to the soil as the weeds decay. When the grove floor is covered with vegetation, it will insulate the soil, keeping it cooler in the summer and warmer in the winter. However, during the winter, groves that have a thick mat of vegetation may have an air temperature some 2-4°F cooler than a grove without a thick mat of vegetation (Krezdorn & Martsolf, 1984; Singh & Tucker, 1984) on calm nights

when radiation cooling is high, thereby increasing the chances of freeze damage to the citrus tree on marginal freeze events. Warmer grove temperatures have also been noted in Texas in groves that are weed free vs. those that are sodded (Leydon, 1969). Groves with a thick mat of vegetation during the dry months have an increased chance of damage by fire if the vegetation is ignited. A positive effect of grove floor vegetation is that, as the material decomposes, it will add organic matter to the soil surface, which will increase the soil's ability to hold water and nutrients for future plant use. Additionally, some leguminous species, such as perennial peanuts, actually provide nutrients to the soil via nitrogen fixation (Neff, 1997). In groves that are extremely wet due to temporary flooding, the existing vegetation can aid in the removal of excess water via transpiration, thereby reducing potential water damage to citrus trees.

Weed Control Program(s)

Preventive programs are most frequently overlooked as a method of weed control that should be incorporated into today's citrus production practices. Preventive programs entail the use of such practices as sanitation, spot spraying, or hand labor to prevent the source of weed infestation (seed and/or vegetative) from widespread dissemination throughout a given area. By removing the undesirable weed species prior to seed development, dissemination by wind or mechanical transport on equipment can be effectively delayed. Some examples of difficult-to-control species for which preventive weed control methods are beneficial are milkweed vine (*Morrenia odorata),* guineagrass (*Panicum maximum)*, balsmapple (*Momordica charanta*), goatweed (*Scoparia dulcis*),

and cogongrass (*Imperta cylindrica*). While preventive practices may not completely stop the spread of weeds, these practices may slow the spread of undesirable weed species, thereby reducing the cost of current programs.

Weed control programs will vary from location to location within the state and can even vary within a given site based upon specific conditions such as soil type, variety, method of herbicide application, and the presence of specific weed species. Herbicides used in citrus groves are generally divided into two groups: (1) soil-applied preemergence herbicides that should be applied before weed seed germination and (2) foliar-applied postemergence herbicides that are applied after the germination of the weed seed. The postemergence herbicides can be further divided into systemic or contact. Systemic herbicides are translocated within the target plant (Singh & Tan, 1992), killing the foliage and root system of the contacted weed. Contact herbicides kill only the plant parts made wet by the spray surface. Selective herbicides kill some plants without significantly injuring other plants. Nonselective herbicides kill all plants present if applied at the correct time and rate. Each chosen method of weed control and herbicide selected have its own advantages and disadvantages. The most frequently chosen methods of weed control are chemical weed control and mowing with the use of tillage or cultivation, which is becoming less common in most areas of the state due to the damage that tillage causes to the fibrous roots, which are very close to the soil surface (Tucker et al., 1980). The use of low volume irrigation systems prohibits cultivation in more than one direction. Most groves that use low volume irrigation will use some type of chemical weed control program to keep the area under the tree nearly weed free for most of the year because

weeds can affect the distribution pattern of most low volume under-tree irrigation emitters and can intercept soil-applied pesticides.

In addition to under-tree herbicide application, the use of chemical mowing is increasing each year as the cost of mechanical mowing increases due to rising equipment and maintenance costs. Chemical mowing consists of using sublethal rates of systemic herbicide to suppress the growth and/or regrowth for up to 45-90 days of grasses and broadleaf weeds that grow in the row middle (Singh & Tucker, 1997).

Herbicides are generally applied two or three times per year, and the total annual amount of herbicide materials will be nearly the same regardless of the application frequency. For preemergence materials, applications should be properly timed so that the maximum amount of herbicide is in the upper soil profile (0 to 3 inches) slightly before peak weed emergence. Materials applied too early will not have enough herbicide concentration to provide adequate weed control due to herbicide losses caused by leaching or degradation on the soil surface or within the soil profile. Some growers will alternate between products in an effort to choose those that will provide the greatest weed control for the given site and weed species present. Once adequate weed control has been achieved, the grower may consider reducing the frequency of application or reducing the rate of the material applied. The areas between the trees in the row middle are mechanically mowed or mowed chemically, except in some areas of the state that are very sandy. Those well drained, sandy sites may use some tillage instead of mechanical mowing (Tucker et al., 1980).

The selection of a herbicide and its rate will vary depending upon the (1) weed species present, (2) growth stage of the weed species, (3) soil type, (4) cost of herbicide material(s), (5) scion variety, and (6) tree age. Generally speaking, young groves will require greater attention to material selection and rate because the areas around the tree are more sun exposed and have greater weed pressure than do larger trees, which have greater shaded areas with lower weed pressure. Young trees generally will not tolerate herbicide rates as high as a mature tree. An exception to the lower weed pressure for mature trees is where vines are present. Vines can germinate in shaded areas and grow into the tree canopy, creating a host of problems for the tree and fruit harvesting operations.

Herbicide band width varies, with a narrower band of 4 feet on both sides of the tree, for a total band width of 8 feet or more used around young trees. As the tree matures, the band width may increase from 5 to 8 feet on each side of the tree, depending on the planting width between the tree rows, with the larger band width used in the wider row spaced planting. Herbicides can be applied alone in water or, in some cases, mixed with suspension fertilizers (depending on herbicide compatibility) to combine the two operations into a single pass through the grove, thereby reducing the application cost. In groves with a well-designed irrigation system that has back-flow prevention devices meeting the approval of the Florida Department of Agricultural and Consumer Services regulations, some herbicide material(s) can be mixed with the irrigation water and applied via the irrigation system. This is referred to as chemigation (Sawyer & Oswalt, 1983) or herbigation (Davies & Albrigo, 1994), if the materials have herbicidal properties only. If chemicals are injected into the irrigation system, all efforts should be taken to make sure

the system is fully operational and to apply an equal amount of water with the herbicide per unit area. Growers should note that all materials cannot be applied in this manner, and they should fully read the chemical label and follow the directions printed on the label in their possession.

Herbicide selection is important in that the grower should know the weed species present in the grove and choose a material or materials that will provide adequate control of all weed species present.

Weeds are classified based upon grouping species together whose similarities are greater than their differences. Category classifications can include broadleaf, grasses, and sedges. Broadleaf (dicotyledons) have broad leaves with net-like veins, display branching growth habit and generally reproduce by seeds. Grasses (monocotyledons) have narrow, strap-shaped leaves and rounded stems, are generally perennial, and reproduce by seeds and/or rhizomes or underground stems. Sedges are similar to grasses but have triangular stems. Sedges may reproduce by seeds, rhizomes or tubers.

Dicotyledon and monocotyledon weeds can be further classified as annuals, biennials, or perennials. Annuals complete their life cycle in one growing season. Annuals may be further classified as either summer annuals, which complete their growth in the spring to fall, or winter annuals, which complete their life cycle from fall to spring or early summer. Biennials require two growing seasons to complete their life cycle, forming rosettes in the first season of growth, then flowering, producing seeds, and dying in the second season. Perennials live for 2 or more years, sometimes living indefinitely.

Perennial weeds are especially difficult to control with contact herbicides due to the underground storage organs that many species contain.

Very few herbicide materials will control grasses (annual and perennial), broadleaf weeds, and vines, thus requiring the application of more than one product to provide broad spectrum control. Rotation of soil-applied herbicides should also be considered to prevent the buildup of resistant annual and perennial weeds. The resistant species may not be evident initially; however, if the same herbicide and cultural program is maintained, over time their populations may build up until they infest the entire grove and become the dominant weed species (Jordan et al., 1992).

Before herbicide application, growers should survey the grove and determine the stage of growth and type of weeds for that given location. Many products do not provide control of emerged species, thus requiring the application of more than one product to provide both preemergence and postemergence protection.

Mechanical mowing is generally more expensive than tillage due to the cost of equipment, equipment maintenance, and energy requirements. Mechanical mowing can also throw seeds under the tree canopy, increasing weed pressure in that area. However, groves are rarely cultivated if they are located in flatwoods with soils that are inherently poorly drained and if the trees are planted on raised middles or beds (Spyke et al., 1977).

In the early 1900s weed control consisted mainly of hand hoeing (flatweeding) and the use of implements that would allow shallow cultivation. All plowing was done prior to planting or was limited to the row middles when the trees were young and did not have roots present in row middles (Hume, 1903, Chilton, 1908). Growers were encouraged to

allow or plant species that would improve the soil, such as beggarweed or velvet bean, as a cover crop. Cover crops would then be cultivated into the soil to improve the humus, thereby increasing the water- and nutrient-holding capacity of the soil. When the soil became very dry from lack of rainfall, it was recommended to cultivate the soil lightly to reduce the water loss due to evaporation from the soil or from transpiration by the weed species growing in the soil. Since this was before the invention of the tractor, the horse and harrow were used. Groves planted on "low hammock" soils would require considerable drainage, so less cultivation would be needed during the year as the soils generally held more water (Pattillo, 1921).

In the 1920s it was generally recommended when the trees had attained considerable size, cultivation be very shallow and that three or four hoeings be done during the year. Shallow cultivation minimizes damage to fibrous roots close to the soil surface. All cover crops were recommended to be cultivated in the autumn (October or November) to improve the organic matter in the soil and minimize potential tree injury by fire if the vegetation were to burn (Hume, 1926). Frequent hand hoeings were abandoned in the 1930s due to the expense (Camp, 1954). During the early years of a grove, growers were encouraged to plant leguminous plants such as hairy indigo, beggarweed, velvet beans, cowpea, crotalaria, or a cover crop in the row middle to build up the organic matter of the soil (Florida Department of Agriculture, 1939). Cultivation of young groves would be confined to the immediate vicinity of the tree to keep this area weed free. When cultivation did occur, efforts would be made to run the harrow as close as possible to the trunk without damaging the tree to remove the maximum amount of weeds (Camp, 1954,

1960). This cultivation method was still the recommendation in 1961 (Ziegler & Wolfe, 1961).

Little change occurred in weed control practices in Florida, with the exception of the use of mechanical tree hoes, until the 1950s when experiments were conducted on the herbicidal effects of various refined petroleum oils on weed growth (Reitz & Long, 1953, 1954). In California the use of phytotoxic oils dates back to the late 1930s (Day & Jordan, 1969). During the late 1950s the cost of weed control around young trees by mechanical methods was \$13 to \$17 per acre per year and \$20 to \$25 per acre per year for hand hoeing (Burt & McCown, 1959). Even with the above methods, the control of weeds, especially perennials, was not satisfactory.

By the late 1950s and early 1960s, numerous reports can be found of successful chemical weed control in various experiments (Burt & McCown, 1959; Kretchman, 1959, 1960a, 1960b; McCown & Kretchman, 1962). The first extensive commercial use of herbicides was in 1964 (Ryan, 1969). In experiments conducted in the 1960s, researchers began to report that young trees treated with diuron or simazine starting one year after planting had greater tree growth than trees that were mechanically hoed (Ryan, 1965a; Ryan & Kretchman, 1968). Treatments with better weed control also resulted in larger trees and subsequent greater yield (Ryan, 1969), beginning both successful and economical weed control. By 1975, at least one publication was discussing herbicide use and listing the benefits of chemical weed control; the authors did mention that this area was rapidly changing due to material development and changing techniques (Ziegler & Wolfe, 1975). Mention was also made of plant bugs and grasshoppers feeding and

reproducing on cover crops and the problems these pests caused the citrus when cover crops were removed during the fall cultivation.

Herbicides Used in this Study

In the experiments conducted in this study, the seven herbicides examined were bromacil, diuron, norflurazon, oryzalin, oxyfluorfen, simazine, and thiazopyr. The herbicides are listed in Table 2-2 by their common names, trade names, chemical families, and chemical names.

Throughout this study numerous experiments have been conducted looking at the effects of seven different herbicides on weed control in field studies, seedling growth and movement within the soil profile using soil columns. Each product will be discussed individually as to the current and past product use rate and mode of action.

Bromacil

Bromacil was introduced for noncrop use in 1963 for control of annual and perennial grass weeds (Ryan, 1966) and is currently registered for the preemergence control of annual and perennial grasses and annual broadleaf weeds. Bromacil does have limited postemergence activity which is enhanced by the addition of a surfactant to the spray mixture (Singh & Tucker, 1997). Early studies used bromacil at rates as high as 30 lb/A (pounds per acre) of product (24 lb ai/A (pounds of active ingredient per acre)) for the eradication of torpedograss from large areas prior to planting a citrus grove (Ryan, 1965b). While this practice may not seem economically advisable, it was justified to prevent the spread of torpedograss into large areas. Repeated applications at six- to

Table 2-2. Common name, trade name, chemical family and chemical names of herbicides used in this study.

Common Name	Trade Name	Chemical Family	Chemical Name
bromacil	Hyvar 80WP	uracil or substituted uracil	5-bromo-6-methyl-3-(1-methylpropyl)-2,4(*1H*, *3H*)pyrimidinedione
diuron	Direx 80DF	phenylurea, substituted urea or urea	*N'*-(3,4-dichlorophenyl)-*N*,*N*-dimethylurea
norflurazon	Solicam 80DF	pyridazinone or fluorinated pyridazinone	4-chloro-5-(methylamino)-2-(3-(trifluoromethyl)phenyl)-3(*2H*)-pyridazinone
oryzaline	Surflan 80DF	dinitroaniline	4-(dipropylamino)-3,5-dinitrobenzenesulfonamide
oxyfluorfen	Goal 1.6E	diphenylether or nitrodiphenylether	2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-
simazine	Princep-Caliber 90DF	trizine or *s*-triazine	2-chloro-*N*,*N'*-diethyl-1,3,5-triazine-2,4-diamine
thiazopyr	Mandate 2E	pyridine	methyl2-(difluoromethyl)-5-(4,5-dihydro-2-thiazolyl)-4-(2-methylpropyl)-6-(trifluoromethyl)-3-pyridinecarboxylate

eight-month intervals at rates of 3 or 6 lb/A (2.4 or 4.8 lb ai/A) reduced torpedograss around citrus trees by 53% to 85%, respectively (Ryan, 1965b). The year of bromacil registration was not determined: however, the product was recommended for use by 1970 (Whitney & Phillips, 1970). By 1971 the use rates were 2.4-3.2 lb ai/A for nonbearing and bearing groves with a maximum annual rate of 6.4 lb ai/A (Tucker et al., 1971). The 1971 recommendations for nonbearing trees were that bromacil should not be applied to trees less than 4 years of age. By 1971, bromacil was also being recommended for use in conjunction with diuron. For weed encroachment barriers, bromacil rates of 16-25 lb ai/A were recommended, and for burrowing nematode buffer zones, bromacil was

recommended at 24 lb ai/A (Tucker et al., 1971). By 1979 bromacil was recommended at lower rates for young trees (1 to 4 years of age) at 1.6-3.2 lb ai/A with a maximum rate of 4.0 lb ai/A per year (Tucker, 1979). From 1990-1993 the rates were reduced for the ridge with a maximum rate per acre of 4.2 lb ai/A and 6.4 lb ai/A for the flatwood citrus region (Tucker & Singh, 1990, 1993). Beginning in 1994 the product label prohibits bromacil from being applied on vulnerable, deep, sandy ridge-type soils, thus limiting its use to the flatwood citrus production region of the state of Florida (Tucker & Singh, 1994). The product is currently applied preemergence with limited postemergence activity up to 6.4 lb ai/A per year for weed control in Florida citrus (Singh & Tucker, 1997). Current use rates are shown in Table 2-3.

Table 2-3. Bromacil use rates in 1997.

Tree Age	Recommended Application Rate	Maximum Annual Rate per Treated Acre
> 4 years	1.6-3.2 lb ai/A	6.4 lb ai/A in flatwoods, prohibited on ridge
1-3 years	1.6-2.4 lb ai/A	6.4 lb ai/A in flatwoods, prohibited on ridge
< 1 year	1.6-2.4 lb ai/A	6.4 lb ai/A in flatwoods, prohibited on ridge

Over the years the product rate per acre has decreased due to better weed management practices and the concern for bromacil being found in the groundwater.

Groundwater contamination is currently a major factor in the use of bromacil in many locations in the state that have vulnerable soils (Power, 1996).

The mode of action for bromacil inhibits photosynthesis by blocking electron transport through photosystem II (PS II), which occurs in the chloroplast lamellae. The blocking of PS II is phytotoxic due to peroxidation of membrane lipids. Lipid peroxidation damages and destroys membrane integrity which will result in loss of cellular compartmentalization (Anderson, 1996).

Diuron

Diuron (along with simazine) was one of the first two herbicides registered for use in Florida citrus (Ryan, 1969) and was recommended in a University of Florida publication by 1962 (Kretchman & McCown, 1962). Early registration was for control of annual weeds, while today's registration is for the control of annual broadleaf weeds and annual grasses (Singh & Tucker, 1997). The earliest recommended rate was 3.2-4.8 lb ai/A with only one application per year (Kretchman & McCown, 1962). Diuron at 6.4 lb ai/A prevented weed growth in 74% of the treated areas for six months, but severe injury due to diuron was observed on trees that had been damaged by freezing temperatures the prior year (Kretchman, 1960b). Additional rates of 20-40 lb ai/A were recommended for weed encroachment barriers and burrowing nematode buffer zones (Kretchman & McCown, 1962). By 1966 the rates for diuron at the upper end of the recommendation had been increased to 6.4 lb ai/A from the 4.8 lb ai/A (Ryan & Davis, 1966) with the lower recommended rate remaining at 3.2 lb ai/A. In 1979 the rates had been reduced to 1.6-4.8 lb ai/A from 3.2-6.4 lb ai/A with a maximum annual rate of 6.4 lb ai/A on ridge

soils (Tucker, 1979). Further, it was recommended that the rates for poorly drained flatwood soils and bedded groves not exceed 3.2 lb ai/A in an application (Tucker, 1979). By 1988 the rates were reduced once again to 1.6-3.2 lb ai/A with a maximum annual rate of 6.4 lb ai/A (Knapp et al., 1988) and have remained at this rate to the present time (Singh & Tucker, 1997).

Table 2-4. Diuron use rate in 1997.

Tree Age	Recommended Application Rate	Maximum Annual Rate per Treated Acre
> 1 year	1.6-3.2 lb ai/A	6.4 lb ai/A on ridge soils, no mention of flatwoods
< 1 year	1.6 lb ai/A	6.4 lb ai/A on ridge soils, no mention of flatwoods

The mode of action for diuron is that the herbicide inhibits photosynthesis by binding onto the pigment protein of PS II, thereby interfering with electron transport in the thylakoid membrane of the chloroplasts. In addition to affecting electron transport, free radicals are also produced, hastening with the death of the plant (Anderson, 1996).

Norflurazon

Norflurazon first appeared in University of Florida recommendations in 1985 at a rate of 3.2-4 lb ai/A with a maximum rate of 8 lb ai/A per year. Norflurazon should be applied prior to weed emergence and should be incorporated with rainfall or irrigation for best results (Knapp et al., 1985). Norflurazon is recommended for the control of annual grasses and certain broadleaf weeds. The recommended rate per acre remained unchanged from 1985 until 1995 when it was reduced to 2.4-4 lb ai/A (Singh & Tucker, 1995).

Norflurazon can be injected through low volume under tree irrigation systems. Current recommendations are shown in Table 2-5.

Table 2-5. Norflurazon use rates in 1997.

Tree Age	Recommended Application Rate	Maximum Annual Rate per Treated Acre
All	2.4-4 lb ai/A	8 lb ai/A

The mode of action for norflurazon is that it acts as a plant pigment inhibitor, restricting the biosynthesis of carotenoids, thus allowing the photodegradation of chlorophyll to occur which causes susceptible plants to become chlorotic or bleached in appearance.

Oryzalin

Oryzalin first appeared in University of Florida recommendations in 1993 at a rate of 2-4 lb ai/A with a maximum annual rate per acre of 6 lb ai/A (Tucker & Singh, 1993). Oryzalin is recommended for the control of annual grasses and certain broadleaf weeds. Oryzalin will not control perennial grasses or weeds that have germinated prior to application. To obtain maximum control, oryzalin should be incorporated into the soil with 0.5 to 1.0 inch of rainfall or irrigation. Oryzalin can be injected into the low volume irrigation system.

The mode of action of oryzalin is inhibition of mitosis. When cell division is disrupted, chromosomes cannot move to the polar end of the nucleus, thus the cell cannot

elongate. Root tips affected by oryzalin will be swollen or club shaped (Anderson, 1996).

Table 2-6. Oryzalin use rates in 1997.

Tree Age	Recommended Application Rate	Maximum Annual Rate per Treated Acre
All	2-4 lb ai/A	6 lb ai/A

Oxyfluorfen

Oxyfluorfen was first listed in 1989 in the Florida Citrus Spray Guide in the section on products registered for use on Florida citrus. This 1989 listing stated the product is for nonbearing use only and did not appear in the general section on weeds (Knapp et al., 1989). As of 1997, the product listing status has not changed since it is still omitted from the weed treatment guide section (Singh & Tucker, 1997).

The product label for oxyfluorfen currently states the product is for nonbearing citrus use, which means that the trees should not produce fruit for a period of 12 months after the last application. Current use rates, as stated on the label, is for a postemergence application of 0.5-2.0 lb ai/A or a preemergence application of 1.2 to 2.0 lb ai/A per treated acre. The maximum use per acre is 4.0 lb ai/A during a 12 month period. Current use rates are listed in Table 2-7.

The mode of action for oxyfluorfen is that the herbicide affects an enzyme of the chlorophyll (protoporphyrinogen IX oxidase or Protox), leading to uncontrolled autooxidation of the substrate. Lipids and proteins are attacked and oxidized by the

Table 2-7. Oxyfluorfen use rates in 1997.

Tree Age	Recommended Application Rate	Maximum Annual Rate Per Treated Acre
Nonbearing	0.5-2.0 lb ai/A	4.0 lb ai/A

above reactions, which damage the cell membranes and cause leakage, thus allowing the cells to disintegrate and dry.

Simazine

Simazine (along with diuron) was one of the first two herbicides registered for use in Florida citrus (Ryan, 1969) and was recommended in University of Florida publication in 1962 (Kretchman & McCown, 1962). Early registration of simazine was for the control of annual weeds while today's registration is for the control of broadleaf weeds, annual vines, and annual grasses (Singh & Tucker, 1997). Simazine does not control perennial grasses or have contact activity (Singh & Tucker, 1997). The early recommended rate was to apply 6.4-9.6 lb ai/A once per year for both bearing and nonbearing trees at least one year of age (Kretchman & McCown, 1962). Early studies showed that simazine was very safe on trees, and rates up to 40 lb/product/A were apparently tolerated by citrus trees (Kretchman, 1960b). At 8 lb ai/A simazine provided 88% weed control at six months after treatment, whereas at 4 lb ai/A it was less effective but gave satisfactory control (Kretchman, 1960b). In 1966 the maximum rate per acre was the same, but recommendations called for a split application on nonbearing trees (Ryan & Davis, 1966). Unlike bromacil and diuron, simazine was not recommended for

use in weed encroachment barriers or in burrowing nematode buffer zones in the 1960s (Kretchman & McCown, 1962, Ryan & Davis, 1966, Tucker et al., 1969). In 1971 the maximum rate per acre was reduced from 9.6 to 8.0 lb ai/A with a note to use no more than 3.2 lb ai/A in bedded groves per application (Tucker et al., 1971). The recommended rate remained constant from 1971 through 1976 (Tucker et al., 1976). In 1979 the maximum annual rate per acre was increased from 8.0 lb ai/A back to the 9.6 lb ai/A with an additional statement that simazine should not be applied to trees less than four years of age in the flatwood areas on raised beds (Tucker, 1979). In 1984 the rates were the same as in 1979 but that the requirement that simazine not be used on trees less than four years of age in the flatwood areas was removed and replaced with a statement of caution that applications should not exceed 3.2 lb ai/A per application on poorly drained soils for trees one to four years of age. The next rate-per-acre change occurred in 1989 when the recommended application rate was reduced to 2.25-6.3 lb ai/A with a maximum annual rate of 9.54 lb ai/A with the lower rate recommended for trees less than two years of age (Knapp et al., 1989). The next year the per application rate was again adjusted, to 2.25-4.5 lb ai/A with the maximum annual rate per acre remaining constant at 9.54 lb ai/A (Tucker & Singh, 1990). In 1991 the rates were reduced again to 2.25-3.96 lb ai/A per application and 7.92 lb ai/A maximum annually with the lower rates for trees less than one year old (Tucker & Singh, 1991). The 1991 rates for simazine have remained constant to 1997 (Singh & Tucker, 1997). Current recommended rates are shown in Table 2-8.

Table 2-8. Simazine use rate in 1997.

Tree Age	Recommended Application Rate	Maximum Annual Rate Per Treated Acre
> 1 year	2.25-3.96 lb ai/A	7.92 lb ai/A
< 1 year	2.25 lb ai/A	3.6 lb ai/A

The mode of action of simazine is that the herbicide inhibits electron transport in PS II by preventing the conversion of light energy into electrochemical energy from the chlorophyll to PS II reaction center. As these reactions occur, the products interact with fatty acids via lipid peroxidation, destroying membrane integrity by attacking lipids and proteins and causing a loss of chlorophyll and carotenoids in membranes, which leak, allowing the cell to disintegrate and dry (Anderson, 1996).

Thiazopyr

Thiazopyr is a new compound that obtained registration for use in Florida citrus in May of 1997. Thiazopyr is a preemergence herbicide for the control of annual grasses and broadleaf weeds in citrus crops. The product can be applied in a single application or in two or three separate applications. The recommended application rate is 0.125-0.5 lb ai/A. The maximum annual rate per acre is 1 lb ai/A. For maximum weed germination rainfall or irrigation is needed within 7 days of application to move the herbicide into the germinating zone of the weeds. Thiazopyr should not be applied within 90 days of harvest. Current rates are shown in Table 2-9.

Table 2-9. Thiazopyr use rate in 1997.

Tree Age	Recommended Application Rate	Maximum Annual Rate Per Treated Acre
All	0.125-0.5 lb ai/A	1 lb ai/A

The mode of action for thiazopyr is that it is a mitotic inhibitor affecting the plant's cell division by interfering with the micro-tubule formation that is required for cell division, producing a club-shaped root tip (Ahrens, 1994).

Other Preemergence Herbicides Used in Florida Citrus

In addition to the previously discussed herbicides, a number of preemergence herbicides are either no longer recommended or lack current pesticide registration.

Dalapon was marketed under the trade name Dowpon and first recommended in 1962 for bearing trees at least four years of age. A series of three applications was applied two to four days apart at 1.5-3.0 lb ai/A (Kretchman & McCown, 1962) for the control of perennial grasses. Dalapon was a systemic herbicide, which was absorbed by the leaves and translocated throughout the plant tissue and into the roots and rhizomes. Dalapon remained in the University of Florida publications through 1979 with the lower rate remaining constant and the upper rate being decreased to 1.5 lb ai/A in 1966 (Ryan & Davis, 1966) and raised to 2 lb ai/A in 1971 (Tucker et al., 1971). Dalapon was no longer recommended after the University's 1979 publication.

Trifluralin is marketed under the trade name Treflan. It was first recommended in 1969 for nonbearing groves as a preemergence, nonselective, root-absorbed herbicide at a rate of 1-2 lb ai/A for the control of annual broadleaf weeds and annual grasses. Trifluralin should be immediately incorporated by mechanical hoe after application (Tucker et al., 1969) due to its very low water solubility of less than 1 ppm, which makes incorporation by rainfall very unlikely. The rates remained constant from 1969 until 1988 with the addition of bearing groves as an application site in 1971 (Tucker et al., 1971). The use of trifluralin first appeared as a water ring treatment in 1984 (Knapp et al., 1984). The recommended use in bearing grove sites was dropped in 1989 (Knapp et al., 1989); however, the water ring treatment recommendation remained in effect until 1991 (Tucker & Singh, 1991). Trifluralin does not currently appear in the University of Florida recommendations.

Terbacil is marketed under the trade name Sinbar. It first appeared in the University of Florida recommendations in 1969 as a preemergence herbicide that was root absorbed for the control of annual weeds and perennial grasses (Tucker et al., 1969). Application rates were 3-4 lb ai/A, and it was recommended that it not be applied to trees less than one year old (Tucker et al., 1969). In 1971 a maximum annual rate per acre of 6.4 lb ai/A was added along with the recommendation that the material should be incorporated into the soil by irrigation or rainfall (Tucker et al., 1971). In 1979 the rates were reduced from 3-4 lb ai/A to 2.4-3.2 lb ai/A (Tucker, 1979). From 1984 until 1989 the rate for trees greater than one year of age remained the same as the 1979 rate; however, a rate was added for trees less than one year of age of 2-3 lb ai/A with a

maximum annual rate of 4.8 lb ai/A in six months and a maximum rate of 6.4 lb ai/A in a twelve month period (Knapp et al., 1984). Terbacil no longer appears in the University of Florida recommendations.

Dichlobenil is marketed under the trade name Casoron. It was added to the University of Florida recommendations in 1969 for the control of annual broadleaf weeds and annual grasses at a rate of 4-6 lb ai/A (Tucker et al., 1969). The application rates were decreased in 1971 to 3-6 lb ai/A with a maximum annual rate of 6.4 lb ai/A (Tucker et al., 1971). Vines were also added to the list of controlled weeds in 1971. Dichlobenil last appeared in the University recommendations in 1979 (Tucker, 1979).

Ametryn is marketed under the trade name Evik. It first appeared in the University of Florida recommendations in 1979 for the control of broadleaf weeds, annual grasses and some perennial grasses. The recommended rate of ametryn was 3.2-6.4 lb ai/A with a maximum rate of 4.8 lb ai/A for shallow, poorly drained flatwood soils and bedded groves. It was recommended that ametryn not be applied to trees less than two years of age. Between 1984 and 1988 the application rates were increased above the 1979 recommended rates to 6.4-9.6 lb ai/A with the annual rate per acre not to exceed 12 lb ai/A and the lower rates being used on young trees (Knapp et al., 1984, 1988). For the two-year period 1989-1990, the rates were decreased to 4.8-6.4 lb ai/A with a maximum annual rate per acre of 9.6 lb ai/A (Tucker & Singh, 1990; Knapp et al., 1989). Ametryn does not currently appear in the University of Florida recommendations.

Postemergence Herbicides Used in Florida Citrus

Paraquat appeared in the University of Florida publications from 1969-1987 and was changed to paraquat dichloride with the trade name Gramoxone in 1986-1997 (Tucker et al., 1969) until the present (Singh & Tucker, 1997) for the postemergence burn down of all weeds. From 1986 until 1987 both paraquat and paraquat dichloride were recommended for use in Florida citrus (Knapp et al., 1986, 1987). The rate was 0.5-1 lb ai/A in 1969 and was slightly adjusted in 1994 to 0.625-0.9375 lb ai/A (Tucker & Singh, 1994). Paraquat dichloride is still currently recommended in University of Florida publications.

Glyphosate is marketed under the trade name Roundup. It first appeared in the University of Florida recommendations in 1979 as a nonselective, systemic herbicide that is actively translocated from the leaf and stem tissue to the roots or rhizomes of the weed. Glyphosate is registered for postemergence use for total or partial control of most weed species (Tucker, 1979). Glyphosate does not have any soil activity for preemergence weed control. The 1979 rates were 1.5-3.75 lb ai/A with an annual maximum of 7.95 lb ai/A. Recommendations cautioned growers not to apply to trees which were less than two years of age and to avoid green bark, tree foliage and fruit. Glyphosate was recommended to be applied in 20-100 gallons of water per acre. By 1984 the application rates were reduced slightly to 0.75-3 lb ai/A with a lower rate of 0.75-1.5 lb ai/A in 5-20 gallons per acre (gpa) for the control of annual broadleaf weeds and grasses (Knapp et al, 1984). The rates were adjusted slightly in 1985 to 1-4 lb ai/A (Knapp et al., 1985) and

the maximum annual rate per acre was reduced to 5.25 lb ai/A in 1988 (Knapp et al., 1988). Chemical mowing recommendations first appeared in University of Florida publication in 1992 (Tucker & Singh, 1992). Glyphosate currently appears in the University of Florida recommendations and is the most popular postemergence herbicide currently used in Florida citrus production.

Fluazifop-p-butly is marketed under the trade name Fusilade. It was first recommended in 1987 for use in nonbearing citrus for the postemergence control of annual and perennial grasses (Knapp et al., 1987). The 1987 rate for fluazifop-p-butly was 0.25-0.375 lb ai/A (Knapp et al., 1987) with the rates increasing to 0.375-0.5 lb ai/A in 1989 (Knapp et al. 1989). In 1996 with the introduction of the 2E formulation the rates were reduced to the 1987 rates of 0.25-0.375 lb ai/A (Singh & Tucker, 1996). Fluazifop-p-butly currently remains in the University of Florida recommendations.

Sethoxydim was first marketed under the trade name Poast and first listed in University of Florida publications in 1993 (Tucker & Singh, 1993). The trade name was changed to Torpedo in 1994 (Tucker & Singh, 1994). The recommended rate of 03.75-0.469 lb ai/A has remained constant since it was first recommended in 1993 for the postemergence control of annual and perennial grasses (Tucker & Singh, 1993). Sethoxydim remains in current University of Florida recommendations (Singh & Tucker, 1997). Sethoxydim can be used in both nonbearing and bearing citrus groves.

Phytophthora palmivora is the only commercially produced biological microherbicide registered for use in Florida citrus. It is marketed under the trade name De Vine. *Phytophthora palmivora* is used for the control of milkweed vines and was first

recommended in University of Florida publications in 1987 (Knapp et al., 1987). The material is applied from June through September at one pint per acre to moist soil. One pint contains 3.2 x 10^8 live chlamydospores. The product should be kept refrigerated prior to use. *Phytophthora plamivora* did not appear in University of Florida publications in 1994 and 1995 but was listed in 1996 and 1997 (Singh & Tucker, 1995, 1996, 1997).

Herbicide Use in California

Early herbicide use in California differed from that in Florida in that phytotoxic oils and other chemical sprays had been used for controlling weeds back to about 1939 (Day & Jordan, 1969). The use of phytotoxic oils allowed for the development of a weed control system of noncultivation as early as the mid 1930s (Moore, 1977). This system of noncultivation eliminated all tillage; the natural vegetation or weeds were controlled by spraying with herbicidal oils. By the 1960s diuron, monuron, simazine, terbacil, and bromacil had replaced many of the phytotoxic oils in the California citrus weed-control program. By 1978 over 90% of California's citrus orchards were under nontillage weed management practices (Jordan & Russell, 1978). In many cases, the rates at which the herbicides were applied were lower than the rates applied in Florida (Jordan & Day, 1973). In California, herbicide toxicity to plants varies with soil type (Day & Jordan, 1969). It has been noted in both California and Florida that citrus growing in sandy soils with low organic matter will show more toxic effects of herbicides than in heavier soils or soils with high clay content (Day & Jordan, 1969; Jordan, 1978; Tucker, 1979).

Monuron was one of the first soil-residual herbicides registered for use in California (Day, 1955), but in Florida the product was limited to ditches or burrowing nematode sites (Kretchman & McCown, 1962; Ryan & Davis, 1966; Tucker et al., 1969). Most of the herbicide applications are made during the winter when rain assists in the movement of the herbicide into the soil (Jordan et al., 1977). The use of nontillage in California has produced many benefits with little evidence of adverse effects (Jordan & Russell, 1978).

CHAPTER 3
EFFECT OF HERBICIDES ON THE GROWTH OF CITRUS ROOTSTOCK AND LIVE OAK SEEDLINGS

Various studies have investigated the effects of herbicide application on the growth of citrus seedlings (Currey et al., 1977; Castle & Tucker, 1978; Tucker & Youtsey, 1980; Singh & Tucker, 1983, 1984; Singh & Achhireddy 1984; Reddy & Singh, 1993a). Weed control in Florida's citrus nurseries accounts for a significant portion of the annual production cost. Weeds compete with the citrus nursery stock for water, nutrients, and light and affect the environmental conditions and accessibility to the young citrus seedling. Trees that have been damaged with herbicides will remain smaller than trees that were uninjured (Jordan et al., 1992). Most nurseries use some form of chemical weed control due to the unavailability and high cost of hand labor for weeding operations. Many of the herbicides currently registered for use in citrus groves lack recommendations for nurseries or recently planted budded citrus trees. If any of the herbicides in this study affect seedling growth, this could explain effects on tree growth that might occur in the field studies, which will be discussed later in this dissertation.

Three studies (begining in July 1995) were conducted to examine the effects of herbicide applications on young citrus rootstock seedlings over a period of 18 months and were not conducted simultaneously. While all the herbicides used in this study were

labeled for use in commercial citrus groves, not all products contain information about the safety of product use on young citrus rootstock seedlings or the herbicide use in citrus nurseries. Safety information concerning the use of herbicide products near oak trees is also important, since their roots may extend into properties that contain citrus groves treated with herbicides for the control of grasses and broadleaf weeds. A single study was conducted to examine the effect of herbicides on the growth of live oak seedlings. The objective of all of the studies was to evaluate the preemergence herbicides as each relates to the growth of seedlings and their relative phytotoxicity.

Materials and Methods

All seedlings were obtained from commercial sources prior to the beginning of these studies. In Study 1, July of 1995, the seedlings of each rootstock were individually potted into one quart (0.946 liter) styrofoam cups with drain holes containing Candler sand (Hyperthermic, uncoated Typic Quartzipsamments). Seedlings were grown in the greenhouse for 45 days prior to the herbicide treatment. The study was conducted in a randomized block design that was replicated four times. The surface area of the container was measured to calculate the amount of herbicide to apply that would then provide the required active ingredient per acre (ai/A) as listed in Table 3-1. A stock solution was made that allowed the required amount of herbicide to be applied in a solution of 1.7 fluid ounce (fl oz) (50 ml) per container in a single application. By using 1.7 fl oz to apply the herbicide, the entire soil surface area of the pot would be covered, thus providing an even distribution of the required herbicide material. The herbicide solution did not contact the

foliage of the plant but did contact the stem of the plant at the soil line. Plants were watered and fertilized as needed to maintain adequate tree growth.

Table 3-1. List of herbicides and rates.

Common Name	Trade Name	Rates (lb ai/A)
bromacil	Hyvar-X 80WP	0.8, 1.2, 1.6
diuron	Direx 80DF	0.8, 1.2, 1.6
norflurazon	Solicam 80DF	0.8, 1.2, 1.6
oryzalin	Surflan 80DF	0.8, 1.2, 1.6
oxyfluorfen	Goal 1.6E	0.4, 0.6, 0.8
simazine	Princep-Cailber-90 DF	0.9, 1.35, 1.8
thiazopyr	Mandate 2E	0.163, 0.244, 0.325

In Study 2 and Study 3, each seedling was planted in a 1-gallon (3.8 liter) black plastic pot with a diameter of 6.5" (16.5 cm) and a depth of 6.5". The pot contained a drain hole in the bottom as well as four holes located around the side of the container. Prior to adding the soil, approximately 1" (2.5 cm) of river rock was added to the bottom of the pot to improve soil drainage. The potting soil was an Apopka fine sand (loamy, siliceous, hyperthermic Grossarenic Paleudults) collected from an area next to a citrus grove at the Citrus Research and Education Center (CREC) in Lake Alfred Florida in Study 2 and a Chandler sand in Study 3. Seedlings were watered and fertilized as needed throughout the study. Seedlings were grown for 45 days after planting prior to having

one rate of the herbicides applied to the soil surface. The experimental design was a randomized block design and replicated four times for each seedling type.

In Study 2, the individual seedlings were randomly assigned to each treatment with each treatment rate (low, medium, or high) being placed on a given bench containing the two types of citrus and the live oak seedlings. Study 3 improved the blocking utilized to place one of each treatment on a given bench to improve design and results obtained. All seedlings were grown in a greenhouse during the entire experimental period.

Rootstock/Herbicide Interaction Study 1

The objective of the first study was to determine the effect of seven herbicides on the growth of seven rootstock seedlings. The seven rootstocks were Carrizo citrange (*Citrus sinensis* (L.) Osbeck x *Poncirus trifoliata* (L.) Raf.), Swingle citrumelo (*Citrus paradisi* x *Poncirus trifoliata*), Cleopatra mandarin (*Citrus reticulata* Blanco), Benton citrange (*Citrus sinensis* (L.) Osbeck x *Poncirus trifoliata* (L.) Raf.), Smooth Flat Seville (putative hybrid), Sun Chu Sha mandarin (*Citrus reticulata*), and Volkamer lemon (*Citrus volkameriana* Ten. and Pasq.). The herbicides and rates used in the study are listed in Table 3-1. The high rate in this first study would be equal to a low rate that growers might use in a commercial grove situation and is also currently used in several field studies discussed later in this dissertation.

Rootstock/Herbicide Interaction Study 2

This study was conducted to determine the herbicide effects on Carrizo citrange and Swingle citrumelo rootstocks, which currently represent about 72% of the rootstock usage by the Florida citrus nursery industry (Division of Plant Industry, 1997). The lower rate used in this study was the upper rate in the previous study and the rate used in the first year of the field studies. Additional rates of 2x and 4x above the base rate were also applied. The field studies will be discussed in a later section of the dissertation. The herbicides used are listed in Table 3-2. Higher herbicide rates were used in Study 2 since no herbicidal effects on rootstocks were detected in the previous study.

Table 3-2. List of herbicides and rates in Study 2.

Common Name	Trade Name	Rates (lb ai/A)
bromacil	Hyvar-X 80WP	1.6, 3.2, 6.4
diuron	Direx 80DF	1.6, 3.2, 6.4
norflurazon	Solicam 80DF	1.6, 3.2, 6.4
oryzalin	Surflan 80DF	1.6, 3.2, 6.4
oxyfluorfen	Goal 1.6E	0.8, 1.6, 3.2
simazine	Princep-C-90DF	1.8, 3.6, 7.2
thiazopyr	Mandate 2E	0.325, 0.65, 1.3

Live oak (*Quercus virginiana*) seedlings were also included in the study due to the concern that herbicides used in citrus groves may affect oaks in nearby properties due to root encroachment into properties containing citrus groves treated with herbicides for weed control. Statements currently appear on the bromacil label about injury to or loss of desirable trees that can result when the material is either applied or moved into contact with desirable tree roots (Du Pont, 1995).

Rootstock/Herbicide Interaction Study 3

A third study was conducted to determine the effect of bromacil and diuron on five citrus rootstocks as Carrizo and Swingle had different responses to these herbicides in Study 2. The five rootstocks in the Study 3 were Carrizo citrange, Swingle citrumelo, Cleopatra mandarin, Sun Chu Sha mandarin (SCS), and Smooth Flat Seville (SFS). Bromacil and diuron were applied to the soil surface at a rate of 1.6, 3.2, 4.8, or 6.4 lb ai/A. All seedlings were grown for 45 days after planting prior to having one of the rates of either bromacil or diuron applied to the soil surface (Table 3-3).

Table 3-3. Herbicides and rates used in Study 3.

Common Name	Trade Name	Rates (lb ai/A)
bromacil	Hyvar-X 80WP	1.6, 3.2, 4.8, 6.4
diuron	Direx 80DF	1.6, 3.2, 4.8, 6.4

Results and Discussion

In Study 1, at 70 days after treatment (DAT), no clear trends in plant growth differences or phytotoxicity symptoms were noted, thus indicating that the herbicide rates were not high enough to be a limiting factor to plant growth.

Due to the design of Study 2, results reported for that experiment showed differences that are attributed to both replication and herbicide effect; that is, all treatments for a given rate were placed on a single bench in the greenhouse. However, it is felt that in most cases the major difference resulted from the herbicide because the benches are quite close together in this greenhouse, thus minimizing the differences due to replication. At 70 DAT none of the seven herbicides had a major effect on seedling fresh shoot weight of Carrizo citrange (Table 3-4). If future studies were conducted, 70 DAT is most likely too short of duration to get large differences in growth responses unless the herbicide is highly toxic to the seedling. However, the foliage conditions indicated a different result with a somewhat more erratic trend as it relates to the fresh root weight. Both bromacil at the medium and high rates and diuron at the high rate caused veinal patterns in the seedling's foliage that were easily seen. Bromacil at the high rate (6.4 lb ai/A) had 24% of the foliage of Carrizo with slight to moderate veinal pattern and 7% at the medium rate (3.2 lb ai/A) with a slight veinal pattern (Table 3-4). Diuron at the high rate (6.4 lb ai/A) had 20% of the foliage exhibiting a slight to moderate veinal pattern on Carrizo seedlings. Thus, for both bromacil and diuron, with increasing herbicide rates the incidence of foliar patterns increased. However, 70 DAT the products used did not

Table 3-4. Effect of preemergence herbicide on the growth and foliage conditions of Carrizo citrange rootstock seedlings in Study 2.

Herbicide	lb ai/A	Fresh Wt. (grams)		Foliage conditions 70 DAT with % veinal pattern noted
		Shoot	Root	
bromacil	1.60	32.98 a	24.49 b-f	All normal
bromacil	3.20	34.57 a	27.55 abc	7% slight
bromacil	6.40	28.74 a	20.42 ef	24% slight to moderate pattern
diuron	1.60	35.72 a	27.50 abc	All normal
diuron	3.20	33.14 a	25.24 b-f	All normal
diuron	6.40	37.11 a	24.32 b-f	19.5% slight to moderate pattern
oryzalin	1.60	32.68 a	21.50 def	All normal
oryzalin	3.20	33.75 a	28.00 ab	All normal
oryzalin	6.40	34.10 a	23.81 b-f	All normal
thiazopyr	0.33	33.83 a	21.19 def	All normal
thiazopyr	0.65	26.69 a	26.72 bcd	All normal
thiazopyr	1.30	35.82 a	23.27 b-f	All normal
norflurazon	1.60	32.61 a	21.97 c-f	All normal
norflurazon	3.20	37.77 a	22.72 b-f	All normal
norflurazon	6.40	35.84 a	19.93 f	All normal
simazine	1.80	34.48 a	27.44 abc	All normal
simazine	3.60	31.18 a	25.96 b-e	All normal
simazine	7.20	31.95 a	24.51 b-f	All normal
oxyfluorfen	0.80	32.55 a	28.43 ab	All normal
oxyfluorfen	1.60	33.23 a	33.20 a	All normal
oxyfluorfen	3.20	34.63 a	25.00 b-f	All normal
control		31.47 a	28.63 ab	All normal

Mean separation within a column by Waller-Duncan, 5% level of significance.
Means followed by same letter within a column do not significantly differ.

correspond to decreases in seedling growth as measured by fresh shoot weight. Additionally, as new growth emerged on the seedlings toward the end of the treatment period, evidence of foliar patterns was less than had been noted on earlier flushes.

Data presented in Table 3-5 indicate the effect that the seven preemergence herbicides had on the fresh shoot and root weights of Swingle citrumelo rootstock seedlings as well as the noted foliage conditions at 70 DAT. As with Carrizo citrange rootstock, the seven herbicides had little negative effect on the fresh shoot or root weight of Swingle citrumelo at 70 DAT. The only herbicide that produced visible differences was bromacil at the high rate where 7% of the leaves exhibited veinal patterns.

Carrizo had a greater number of leaves with veinal patterns at the high and medium rates of bromacil and at the high rate of diuron than did Swingle. This noted difference between Carrizo and Swingle has been previously reported (Castle & Tucker, 1978). Their findings indicated a higher numerical mean injury score rating for Carrizo than for Swingle at first rating; however, the scores were not statistically different from each other. Their data also agreed with this study in that bromacil produced greater injury to citrus nursery trees than did diuron when used at the same lb ai/A.

In Study 2, the herbicide effects on the growth of live oak seedlings (Table 3-6) were quite different from those for the citrus seedlings of Carrizo and Swingle (Tables 3-4 and 3-5). Bromacil, norflurazon, and diuron had the greatest negative effect on both fresh shoot and root weight and on the foliage conditions of the live oak seedlings. High rates of bromacil, norflurazon, and diuron killed some seedlings. At the low rate (1.6 lb ai/A) of bromacil, 50% of the seedlings died with the remaining 50% severely necrotic; at the

Table 3-5. Effect of preemergence herbicide on the growth and foliage conditions of Swingle citrumelo rootstock seedlings in Study 2.

Herbicide	lb ai/A	Fresh Wt. (grams)		Foliage conditions 70 DAT
		Shoot	Root	
bromacil	1.60	41.32 abc	26.46 b-e	All normal
bromacil	3.20	41.92 abc	28.89 bc	All normal
bromacil	6.40	39.89 abc	22.31 e	7% leaves with veinal patterns
diuron	1.60	43.64 ab	30.40 b	All normal
diuron	3.20	38.11 bc	26.23 b-e	All normal
diuron	6.40	46.39 a	27.62 bcd	All normal
oryzalin	1.60	41.56 abc	26.69 b-e	All normal
oryzalin	3.20	39.08 abc	40.25 a	All normal
oryzalin	6.40	43.76 ab	26.69 b-e	All normal
thiazopyr	0.33	41.64 abc	25.28 cde	All normal
thiazopyr	0.65	43.19 ab	36.64 a	All normal
thiazopyr	1.30	41.63 abc	28.97 bc	All normal
norflurazon	1.60	36.12 bc	25.08 cde	All normal
norflurazon	3.20	38.17 bc	27.02 b-e	All normal
norflurazon	6.40	40.75 abc	23.41 de	All normal
simazine	1.80	41.91 abc	28.51 bc	All normal
simazine	3.60	40.91 abc	24.99 cde	All normal
simazine	7.20	43.73 ab	28.19 bcd	All normal
oxyfluorfen	0.80	40.17 abc	30.87 b	All normal
oxyfluorfen	1.60	35.28 c	30.29 b	All normal
oxyfluorfen	3.20	46.53 a	28.70 bc	All normal
control		40.82 abc	32.40 b	All normal

Mean separation within a column by Waller-Duncan, 5% level of significance. Means followed by same letter within a column do not significantly differ.

Table 3-6. Effect of preemergence herbicide on the growth and foliage conditions of live oak seedlings in Study 2.

Herbicide	lb ai/A	Fresh Wt. (grams)		Foliage conditions [1] 70 DAT
		Shoot	Root	
bromacil	1.60	2.09 ghi	6.78 f-i	D-2 E-2
bromacil	3.20	0.37 i	4.90 hi	D-1 E-3
bromacil	6.40	0.44 i	3.99 i	D-2 E-2
diuron	1.60	5.59 a-e	10.73 b-e	A-1
diuron	3.20	4.81 c-g	7.57 d-h	A-2
diuron	6.40	2.04 hi	6.51 f-i	C-3 E-1
oryzalin	1.60	5.88 a-e	7.51 d-h	All normal
oryzalin	3.20	4.39 c-h	7.34 e-i	All normal
oryzalin	6.40	4.92 b-f	8.06 c-h	All normal
thiazopyr	0.33	6.43 a-d	10.94 bcd	All normal
thiazopyr	0.65	6.20 a-e	12.09 b	All normal
thiazopyr	1.30	3.60 e-h	7.12 f-i	All normal
norflurazon	1.60	4.75 c-h	7.86 d-h	B-1 B&C-2
norflurazon	3.20	3.56 e-h	6.66 f-i	B-1 B&C-2
norflurazon	6.40	2.31 f-i	5.60 ghi	D-2 E-1
simazine	1.80	7.60 ab	16.68 a	All normal
simazine	3.60	4.86 b-g	7.30 e-i	All normal
simazine	7.20	4.14 d-h	8.98 b-g	All normal
oxyfluorfen	0.80	6.38 a-d	11.45 b-e	All normal
oxyfluorfen	1.60	8.25 a	16.29 a	All normal
oxyfluorfen	3.20	6.98 abc	9.96 b-f	All normal
control		7.000 abc	11.32 b	

Mean separation within a column by Waller-Duncan, 5% level of significance. Means followed by the same letter within a column do not significantly differ.

[1] Foliage conditions: A=veinal pattern, B=white, bleached appearance, C=mild necrosis, D=severe necrosis, E=seedling death, number after letter indicates number of seedlings affected.

medium rate (3.2 lb ai/A) 75% died and 25% were severely necrotic; and at the high rate (6.4 lb ai/A) 50% died and 50% were severely necrotic. For norflurazon, at the low rate (1.6 lb ai/A) and medium (3.2 lb ai/A) rate 25% of the seedlings had leaves that were white with bleached appearance, and 50% of the seedlings had leaves that were white with bleached appearance and mild necrosis. For norflurazon at the higher rate (6.4 lb ai/A), 50% of the seedlings had severe necrosis and 25% died. For diuron at the low rate (1.6 lb ai/A) 25% of the seedlings had veinal patterns and the remaining 75% were healthy; at the medium rate 50% of the seedlings had veinal patterns; and at the high rate 75% of the seedlings had mild necrosis and the remaining 25% died.

The impact of increasing herbicide rate, determined by linear regression, on shoot and root weights for citrus and live oak seedlings is listed in Table 3-7, with estimates for the slope of a straight line for the rate/herbicide interaction for each herbicide, rootstock and live oak is provided.

For Carrizo citrange rootstock, increasing herbicide rates did not have a significant effect on fresh shoot weight; however, norflurazon and bromacil had a negative effect on fresh root weight (Table 3-7). Foliar patterns were noted in both bromacil- and diuron-treated seedlilngs, with foliar patterns caused by bromacil more numerous (Table 3-4). For Swingle citrumelo, with increasing rates only norflurazon and bromacil had a negative effect on fresh root weight but did not have a significant affect on fresh shoot weight (Table 3-7). As in Carrizo citrange, foliar patterns were noted and affected only in 7% of the leaves of those trees treated with bromacil at the high rate (6.4 lb ai/A) (Table 3-5).

Table 3-7. Impact of increasing herbicide rate on the fresh shoot weight and fresh root weight of citrus rootstocks and live oak seedlings using linear regression to determine the slope of the line in Study 2.

		Carrizo		Swingle		Live Oak	
		Shoot wt.	Fresh root wt.	Shoot wt.	Fresh Root wt.	Shoot wt.	Fresh root wt.
Rate*Herb Interaction	bromacil	NS	-1.5061 (0.0275)	NS	-1.8412 (0.0021)	-1.9624 (0.0001)	-2.2007 (0.0001)
	diuron	NS	NS	NS	NS	-1.0684 (0.0004)	-1.2799 (0.0021)
	oryzalin	NS	NS	NS	NS	NS	-1.1589 (0.0051)
	thiazopyr	NS	NS	NS	NS	-0.5990 (0.0411)	NS
	norflurazon	NS	-2.1791 (0.0017)	NS	-2.2203 (0.0018)	-1.1751 (0.0001)	-1.6763 (0.0001)
	simazine	NS	NS	NS	NS	NS	NS
	oxyfluorfen	NS	NS	NS	NS	NS	NS

NS = not significant; number in ( ) = P value level of significance.

For live oak seedlings, the regression line data indicate that with increasing rates of herbicides, the shoot and root weights were not significantly affected for simazine and oxyfluorfen treated trees (Table 3-7). Thiazopyr treated trees shoot weight was slightly affected with no significant effect on root weight. Oryzalin had a significant effect on the root weight but not shoot weight. Bromacil, norflurazon and diuron at increasing rates had a significant effect on both shoot and root weight of oaks seedlings. Bromacil, norflurazon and diuron, when applied to live oak seedlings, caused seedling mortality.

In Study 3, for each herbicide treatment, the mean was calculated for the fresh shoot weight, fresh root weight and dry root weight for each of the five rootstocks at 150 DAT; this is shown in Table 3-8. Data were analyzed as a factorial, with the two factors

Table 3-8. Mean fresh shoot weight, fresh root weight and dry root weight for each rootstock and herbicide application rate at 150 DAT in Study 3.

Rootstock	Herbicide	Herb. Rate	Fresh Shoot wt.	Fresh Root wt.	Dry Root wt.	Seedlings with foliar patterns	Percent Leaves injured
		lb ai/A	grams	grams	grams	#	%
Swingle	control	0.00	37.38 a	42.33 a	10.15 a	0	0
Swingle	bromacil	1.60	35.36 ab	42.06 a	9.55 a	2	10
Swingle	bromacil	3.20	24.73 c	22.08 d	5.15 b	4	25
Swingle	bromacil	4.80	27.78 bc	23.67 cd	6.23 b	3	18
Swingle	bromacil	6.40	22.68 c	21.65 d	4.97 b	4	28
Swingle	diuron	1.60	34.58 ab	37.38 ab	9.11 a	0	0
Swingle	diuron	3.20	37.44 ab	35.75 ab	9.21 a	0	0
Swingle	diuron	4.80	42.02 a	35.14 ab	9.07 a	0	0
Swingle	diuron	6.40	41.41 a	31.39 bc	8.96 a	1	6
Carrizo	control	0.00	30.36 ab	25.76 ab	6.79 ab	0	0
Carrizo	bromacil	1.60	25.47 abc	20.59 bc	4.57 bc	2	6
Carrizo	bromacil	3.20	21.53 bcd	19.81 bc	4.30 c	3	27
Carrizo	bromacil	4.80	13.86 cd	15.66 c	3.85 c	4	53
Carrizo	bromacil	6.40	12.00 d	13.84 c	3.16 c	4	33
Carrizo	diuron	1.60	30.04 ab	28.54 ab	7.53 a	0	0
Carrizo	diuron	3.20	35.52 a	32.23 a	8.48 a	0	0
Carrizo	diuron	4.80	29.99 ab	26.58 ab	7.07 a	0	0
Carrizo	diuron	6.40	34.00 a	33.27 a	9.04 a	0	0
Cleopatra	control	0.00	41.54 abc	24.42 bc	7.05 bcd	0	0
Cleopatra	bromacil	1.60	38.64 bc	25.02 bc	6.91 bcd	0	0
Cleopatra	bromacil	3.20	32.75 c	19.81 c	5.24 d	1	9
Cleopatra	bromacil	4.80	44.73 abc	28.88 ab	7.80 bc	1	23
Cleopatra	bromacil	6.40	36.21 c	23.36 bc	6.02 cd	4	20
Cleopatra	diuron	1.60	52.49 a	26.66 abc	8.03 abc	0	0
Cleopatra	diuron	3.20	50.57 ab	34.28 a	10.38 a	0	0
Cleopatra	diuron	4.80	45.24 abc	29.92 ab	8.84 ab	0	0
Cleopatra	diuron	6.40	40.32 abc	30.59 ab	8.90 ab	1	10

Table 3-8--continued.

Rootstock	Herbicide	Herb. Rate	Fresh Shoot wt.	Fresh Root wt.	Dry Root wt.	Seedlings with foliar patterns	Percent Leaves injured
		lb ai/A	grams	grams	grams	#	%
SCS	control	0.00	34.87 a	27.00 a	7.47 a	0	0
SCS	bromacil	1.60	34.34 a	29.75 a	9.00 a	0	0
SCS	bromacil	3.20	37.75 a	29.38 a	8.95 a	0	0
SCS	bromacil	4.80	31.97 a	25.32 a	7.17 a	0	0
SCS	bromacil	6.40	34.84 a	26.55 a	7.56 a	2	16
SCS	diuron	1.60	38.80 a	30.65 a	9.15 a	0	0
SCS	diuron	3.20	31.94 a	22.88 a	6.53 a	0	0
SCS	diuron	4.80	44.01 a	38.03 a	11.56 a	0	0
SCS	diuron	6.40	31.11 a	27.14 a	7.87 a	0	0
SFS	control	0.00	58.24 a	51.59 bc	15.81 ab	0	0
SFS	bromacil	1.60	56.01 a	27.53 d	11.27 ab	3	13
SFS	bromacil	3.20	43.80 a	28.58 d	10.18 b	3	34
SFS	bromacil	4.80	41.87 a	23.91 d	8.23 b	4	40
SFS *	bromacil	6.40					
SFS	diuron	1.60	58.59 a	69.91 ab	16.49 ab	0	0
SFS	diuron	3.20	73.33 a	78.33 a	19.49 a	1	5
SFS	diuron	4.80	59.03 a	56.96 bc	14.19 ab	0	0
SFS	diuron	6.40	53.08 a	49.44 c	12.18 ab	2	17

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
* seedlings discarded due to treatment error.
SCS = Sun Chu Cha
SFS = Smooth Flat Seville

being rootstock and herbicide. Of the five rootstocks, Swingle citrumelo and Carrizo citrange had the only major statistical differences, which were determined using the Waller-Duncan statistical test at a P=.05 level of significance.

From the data presented for Swingle citrumelo rootstock, significant differences were found for fresh shoot weight (4.8 and 6.4 lb ai/A) and fresh root (4.8 and 6.4 lb ai/A) and dry root (3.2, 4.8, and 6.4 lb ai/A) weight. It should also be noted that the 3.2, 4.8 and 6.4 lb ai/A rates are at levels that exceed the normal use rates for young trees. The current rates for trees less than one year of age is 1.6 to 2.4 lb ai/A (Singh & Tucker, 1997). No major differences were determined for diuron at the four rates when the material was applied to the Swingle seedlings. When comparing the means to the control, there is a clear reduction in weights of 39%, 49%, and 51%, respectively, as you increase the herbicide application rates of bromacil for fresh shoot, fresh root and dry root.

From the data collected for Carrizo citrange rootstock in Study 3, statistical differences were determined between the untreated control and when bromacil was applied at rates of 4.8 and 6.4 lb ai/A for fresh shoot weight and at the 6.4 lb ai/A for fresh root weight. No statistical differences were determined for dry root weight at any application rate of bromacil. No major differences were determined for diuron at the four rates when the material was applied to the seedlings. When comparing the means to the control for Carrizo, there is a clear reduction in weights of 61%, 46%, and 53%, respectively, as herbicide application rates increased for bromacil for fresh shoot, fresh root, and dry root.

No statistical differences were noted for Cleopatra or Sun Chu Sha seedlings treated with bromacil or diuron.

Statistical differences in fresh shoot weight were noted when Smooth Flat Seville seedlings were treated with bromacil at the 4.8 lb ai/A and for fresh and dry root weight at the 1.6, 3.2 and 4.8 lb ai/A. No clear trends were noted for the diuron treated Smooth Flat Seville seedlings which were treated. The Smooth Flat Seville seedling at the 6.4 lb ai/A were discarded due to treatment error.

Bromacil applications caused foliar toxicity patterns in greater numbers of seedlings (58%) than did diuron (6%) as noted in Table 3-8. For the bromacil-treated trees, foliar patterns were noted on the following rootstocks: Swingle citrumelo, 81% trees; Carrizo citrange, 81%; Cleopatra mandarin, 38%; Sun Chu Sha, 13%; and Smooth Flat Seville, 83%. For the diuron-treated trees, foliar patterns were noted on the following rootstocks: Swingle citrumelo, 6%; Carrizo citrange, 0%; Cleopatra mandarin, 6%; Sun Chu Sha, 0%; and Smooth Flat Seville 19%. As new growth emerged on the seedlings toward the end of the treatment period, evidence of foliar patterns was less than had been noted on earlier flushes.

The impact of increasing herbicide rates, determined by simple linear regression, on the fresh shoot, fresh root and dry root weight is listed in Table 3-9. Compared to diuron, bromacil had a more significant effect on the growth of three of the five rootstocks (Table 3-9). Bromacil negatively affected growth by reducing fresh shoot weight, fresh root weight, and dry root weight of Carrizo and Swingle and also reducing the fresh root and dry root weight of Smooth Flat Seville. When diuron was applied an increase in dry

root weight was noted for Carrizo and both fresh and dry root weight increased in Cleopatra.

Table 3-9. Impact of increasing herbicide rate on the shoot weight and root weight of citrus rootstock seedlings using linear regression to determine the slope of the line in Study 3. Number in ( ) indicated the level of significance at .05 or less.

		bromacil	diuron
Carrizo	Shoot wt.	-2.4360 (0.0001)	NS
	Root wt.	-1.5869 (0.0003)	NS
	Dry root wt.	-0.4685 (0.0001)	0.2725 (0.0152)
Swingle	Shoot wt.	-1.7350 (0.0001)	NS
	Root wt.	-2.9044 (0.0001)	-1.3038 (0.0123)
	Dry root wt.	-0.6831 (0.0001)	NS
Cleopatra	Shoot wt.	NS	NS
	Root wt.	NS	0.9553 (0.0192)
	Dry root wt.	NS	0.3007 (0.0188)
SCS	Shoot wt.	NS	NS
	Root wt.	NS	NS
	Dry root wt.	NS	NS
SFS	Shoot wt.	NS	NS
	Root wt.	-6.3484 (0.0009)	NS
	Dry root wt.	-1.4912 (0.0054)	NS

Conclusions

These studies show that high rates of herbicides, especially bromacil, can reduce shoot and root growth of citrus seedlings. Growers should be aware of the potential problem and avoid higher application rates on young trees in either new plantings or on resets in existing groves. If only mild phytoxicity symptoms appear on seedlings and additional applications at damaging rates are not applied, then the trees should not suffer long-term damage. This lack of long term damage is also supported by Ryan and Kretchman (1968b). Growers should not assume that all rootstocks will respond similarly to the same herbicide treatment. This study did show differences between Carrizo and Swingle, as noted by the visible differences in bromacil toxicities, as well as differences in root and shoot weights. Carrizo has been previously reported to be more sensitive to herbicides than Swingle (Singh & Achhireddy, 1984). Additionally, data presented indicate that potential problems might occur if applications of bromacil, norflurazon and diuron to citrus planting where live oak roots may encroach into groves could potentially cause damage to live oaks. Growers should use caution when applying these materials to areas where live oak roots may be present.

Studies to determine the effect of herbicides on the growth of seedlings should be longer in duration than was conducted in the second study. Seventy days may not allow a long enough period of time to develop differences in plant growth, especially if the materials are applied during months in which the plant growth is slower. Effects of herbicides on plant growth would have a greater effect if the herbicides were applied during a period of rapid growth in the spring. Citrus nursery trees in Florida generally

have their strongest growth period in the spring and weaker growth periods in the summer and fall. Citrus nursery tree susceptibility to herbicides appear to be related to tree vigor (Castle & Tucker, 1978) and to periods of rapid growth.

Different results may occur in citrus field situations if materials are applied in a manner which allows the herbicide material to contact the citrus foliage, especially if the materials are applied via an overhead irrigation system. Phytoxic symptoms of oxyfluorfen and norflurazon have been reported at rates of one and two lb/A (Singh & Achhireddy, 1984: Singh & Tucker, 1984), whereas this study, even at higher rates, did not produce phytoxic symptoms with either material. If materials are applied via overhead irrigation, the herbicide materials should be washed off with additional irrigation to reduce foliar damage to citrus (Singh & Achhireddy, 1984).

CHAPTER 4
ESTIMATING HERBICIDE MOBILITY USING SOIL LEACHING COLUMNS

Introduction

In recent years greater environmental concern and awareness have arisen in both farm and nonfarm communities regarding the use of soil-applied herbicides. Herbicides in citrus production are increasingly important production tools of commercial citrus for the control of grasses and broadleaf weeds in Florida's 857,687 acres of commercial citrus (Florida Agricultural Statistical Services, 1996a). Florida's subtropical climate, sandy soils, and average annual rainfall of 50 to 70 inches (127 to 178 cm) favor rapid weed growth throughout much of the year but pose unique environmental concerns regarding the leaching of herbicides beyond the zone of weed seed germination and potentially into the groundwater. In 1995, samples from 303 wells in a three-county area in Central Florida showed that 151 of the wells had detectable levels of bromacil (Power, 1996). Bromacil was a commonly used citrus herbicide that has been banned from the Florida's central ridge citrus production region due to water contamination; however, it is still used in nonridge citrus production areas within Florida (Singh & Tucker, 1997). Contamination of groundwater due to herbicide leaching is a concern throughout many major agricultural regions worldwide (Hallberg, 1988). California is also confronted with many groundwater quality issues in citrus and other agricultural crops (Ingels, 1994; Domagalski & Dubrovsky, 1992).

Leaching of chemicals, both herbicides and nutrients, is a major concern due to the potential loss of the chemical, which then no longer provides the needed function, as well as the environmental concerns of groundwater contamination. Once the nutrient has moved beyond the root zone of the plant, or the herbicides beyond the upper soil surface, it no longer provides benefits for the farm system. Any factor(s), environmental, man-made or man-influenced, that contributes to the downward movement of chemicals beyond the intended site of action can prove costly for the farmer and the environment. In most cases, this downward movement of dissolved materials is in the soil solution. The nature of the chemical, any microorganisms, and its reactions with the soil will regulate the mobility and the ultimate quantity available for leaching. The potential for leaching is the greatest when highly soluble chemicals are used in well-drained sandy soils with low organic matter, which is typical of many of Florida's citrus soils (Jackson et al., 1995; Reddy & Singh, 1993b; Singh & Tucker, 1997).

Leaching

Leaching is a process whereby materials (including chemicals and herbicides) are flushed through the soil by rain or irrigation as it moves through the soil profile in the water flow (Rao & Hornsby, 1989). In citrus, all preemergence herbicides require soil incorporation from the site of application on the soil surface by either rainfall or irrigation to the zone of weed seed germination in the top several inches of soil (Tucker, 1979). This is essential since mechanical incorporation has little potential use due to possible damage to citrus roots, low volume irrigation lines, or difficulties of a complete and even

distribution of the herbicide to the entire under-tree canopy area of the citrus tree. Movement or incorporation of the herbicide only to the zone of weed seed germination is beneficial since this provides a mechanism that allows the herbicide to contact the germinating seedling, thus providing control of unwanted weed species, if the proper herbicide and rate were chosen. If the herbicides are not incorporated into the soil, their potential effectiveness is reduced by photodecomposition and/or volatilization into the atmosphere (Jain & Singh, 1992).

When herbicides are leached beyond the zone of weed seed germination, the following can occur: damage to the citrus tree due to greater root contact, poor weed control due to inadequate herbicide concentration around germinating weeds seeds, contamination of groundwater, and monetary losses due to reduced herbicide efficiency.

Factors Influencing Leaching

A number of factors will influence leaching of soil-applied herbicides: adsorption of herbicides to soil colloids, soil texture, soil permeability, volume of water flow, water solubility of herbicides, soil pH, and inorganic and organic soil colloids (Anderson, 1996). While these factors play an important role in herbicide leaching, the farmer does not have full control over them or may not easily change them by agricultural practices other than irrigation scheduling or soil pH adjustment. However, by having information about the factors for a given site, the farmer can more effectively manage agricultural production practices to minimize the leaching potential of applied chemicals.

Adsorption of Herbicides

Adsorption of herbicides to soil colloids is one of the most important factors influencing herbicide leaching (Anderson, 1996; Chiou, 1989). As herbicides become adsorbed to the soil colloids, their leaching is greatly reduced; in fact, if they are strongly adsorbed, they cannot move in the water flow unless the colloids themselves are moved. Herbicides can become desorbed from the soil colloids via ionic exchange, thus allowing the desorbed herbicide ions or molecules to enter the soil solution where they become vulnerable to leaching in the soil.

Soil Texture

Soil texture is the relative proportion of the various size groups (sand, silt, and clay) of individual soil grains in the soil. Sand particles are the largest grains and are rough and irregular in size. Sand particles have a relatively small surface area per unit weight compared to silts and clay. Neither sand nor silt is a charged particle, whereas clay has a negative charge. Soil texture also influences the water-holding capacity of the soil. Soils that are moderately fine textured hold more water than soils that are coarse in texture, such as sand. As the sand content of a given soil increases, the leaching potential of the soil also increases.

Soil Permeability

Soil permeability refers to the ability of a soil to transmit water and air. Permeability estimates the rate of downward movement of water for a saturated soil. Factors that influence permeability are structure, porosity, and texture.

Volume of Water Flow

The volume of water flow at a given point in the soil will tend to increase leaching of herbicides through the soil unless water-impermeable (hard pan) layers restrict water movement.

Water Solubility

Water solubility is an indicator of the ease in which an herbicide can be leached. Solubility is the maximum amount of a given material that will dissolve in pure water at a given temperature and pH. The more water soluble the herbicide, the greater the potential for that product to be leached if it stays in soil solution. Applied materials will have varying degrees of water solubility, thus allowing movement to the site of activation or use. Those products that are highly water soluble will generally remain in the water and move with the water in the soil profile. Materials that are somewhat water insoluble will move from the water (disassociate) in the soil to become attached to the soil aggregate. If the herbicide is water soluble but adsorbed to soil colloids, its leaching potential is greatly reduced.

Soil pH

Soil pH is the negative logarithm of the hydrogen ion concentration in soil solution. The pH affects the availability of many of the chemicals in solution or the ability of the chemical to bind at the binding sites of the soil particles.

Inorganic and Organic Soil Colloids

Inorganic (clay) and organic (humus) soil colloids or particles are extremely small, have a large surface area per unit mass, are a very chemically reactive portion of the soil,

and generally have a negative charge. The negative charge is responsible for the adsorption of water, cations, some pesticides and organic molecules on the surface of the colloidals. These soil colloids provide adsorptive sites for chemicals, thus allowing them to move from the soil solution to become adsorbed to the soil colloid where they are no longer available to be leached in the water flow. As the clay and humic content in the soil increases, adsorption also increases, accompanied by a reduced leaching potential of the herbicide in the soil.

Use of Soil Column as a Technique to Simulate Herbicide Movement in Soil

Mobility of an herbicide is dependent upon the chemical nature of the herbicide compound as well as the chemical and physical properties of the soil (Anderson, 1996). The use of soil columns as a technique to simulate herbicide movement in soil is well documented (Weber et al., 1986). “Natural” and “hand-packed” soil columns are two types used to investigate the leaching behavior of chemicals in soils; the hand-packed method is used in this study.

The primary objectives of this study were (1) to determine the mobility of selected preemergence herbicides at different application rates of water and (2) to compare mobility of the different herbicides.

Materials and Methods

The seven herbicides used in the study were bromacil, diuron, norflurazon, oryzalin, oxyfluorfen, simazine, and thiazopyr. Trade name and rate used are listed in

Table 4-1. Application of water was equivalent to 1.25, 2.5, 3.75, and 5.0 inches (3.2, 6.4, 9.6, and 12.8 cm) of irrigation or rainfall per acre. The experiments were replicated three times.

Table 4-1. Herbicides, trade name and irrigation/rainfall rate used.

Common Name	Trade Name	Application rates	
		Herbicide lb ai/A	Irrigation/rainfall inches
bromacil	Hyvar-X 80WP	6.4	1.25, 2.5, 3.75, 5.0
diuron	Direx 80DF	6.4	1.25, 2.5, 3.75, 5.0
norflurazon	Solicam 80DF	7.2	1.25, 2.5, 3.75, 5.0
oryzalin	Surflan 80DF	6.0	1.25, 2.5, 3.75, 5.0
oxyfluorfen	Goal 1.6E	3.6	1.25, 2.5, 3.75, 5.0
simazine	Princep-Caliber 90DF	7.92	1.25, 2.5, 3.75, 5.0
thiazopyr	Mandate 2E	1.5	1.25, 2.5, 3.75, 5.0
untreated control		0	1.25, 2.5, 3.75, 5.0

Soil was collected in 1-foot (30 cm) increments to a depth of 4 feet (120 cm) of a Chandler sand series (Hyperthermic, uncoated Typic Quartzipsamments) at the Citrus Research and Education Center (CREC) research farm located north of Haines City, FL. This soil is typical of a well-drained ridge soil found throughout Central Florida, where citrus is a major agricultural crop. The collection site was a noncrop area that had not recently been used for agricultural production, thus being free of herbicide treatments and cultivation. The soil was air dried and stored in large wooden containers. The average soil

pH and organic matter for each of the four depths (Table 4-2) were determined using pH (1:2 S:W) and Walkley-Black dichromate methodology, respectively.

Table 4-2. Soil sample analysis data for soil used in split columns.

Depth from soil surface (inches)	Soil pH	% Organic Matter
0 to 12	6.5	0.9
12 to 24	5.3	0.2
24 to 36	5.1	0.2
36 to 48	5.0	0.3

The soil columns were made from 4 inch (10 cm) polyvinyl chloride (PVC) pipes cut to a length of 5 feet (150 cm). The pipe was split longitudinally for the entire length to form two equal halves. On the inside of each half of pipe, beginning 6 inches (15 cm) from the bottom and in increments 6 inches thereafter, a silicone sealer bead or ridge was placed. This ridge of silicone was to prevent water movement down the side of the pipe "edge flow" or "boundary flow" along the soil/wall interface, when filled with soil (Weber & Peeper, 1977; Weber et al., 1986). The split columns were joined using a cap on the bottom and duct tape around the pipe and down the longitudinal cuts to hold it together prior to filling the column with soil. By using tape to join the column, the pipe could be easily split after the herbicide application to allow planting of seeds in the treated soil to determine location of herbicide movement. Figure 4-1 provides a cross-section drawing of the soil column used in this study.

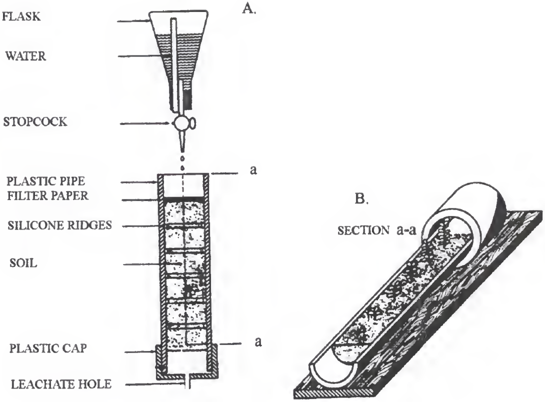

Figure 4-1. Cross-section of hand-packed soil column using a split-column system. Apparatus is set up for unsaturated-flow studies (A). After leaching, column is divided longitudinally to provide two continuous half-columns, which were used for plant bioassay (B). (Adapted from Weber et al., 1986)

The soil was uniformly packed into the leaching columns to simulate the soil profile, as collected in the field. Columns were shaken during filling and saturated with water to aid in soil compaction. Soil-filled columns were kept in the upright position during saturation with water from the top of the column and during leaching of the herbicide. The soil was saturated with water and allowed to drain overnight to field capacity prior to having the herbicides applied to the soil surface. An herbicide solution, of the proper concentration (Table 4-1), in a 1.7 fl oz (50 ml) solution was applied with a small dropper to the soil surface in each of the columns. The herbicide was allowed to equilibrate with the soil for several hours before the leaching process was initiated. Two pieces of filter paper were placed on the soil surface, inside the column, to provide a more uniform distribution of water over the soil surface. The water was allowed to drip from 1000 ml Erlenmeyer flask at a rate equal to 1 inch (2.5 cm) per hour until the entire amount of water (1.25, 2.5, 3.75, 5.0 inches) (3.2, 6.4, 9.6 or 12.8 cm) had been applied. The columns were allowed to drain overnight after application of water and with water prior to splitting the column and planting the bioindicator plant seeds.

The use of growing sensitive plant species in soils that contain toxic levels of herbicides (bioassay or bioindicator) to the chosen indicator plant can be a useful tool for both research and farm studies (Lavy & Santelmann, 1986). This practice dates back over 60 years (Crafts, 1935). Bioindicator plants used in the study were winter rye grass for all herbicides except simazine; sugar beet was used as the bioindicator plant for simazine. The columns were split longitudinally, and three rows of seeds were planted down the entire length of the column. The columns were lightly watered one to two times daily and

fertilized as needed to maintain adequate plant growth. Visual ratings as to the depth of herbicide movement, as indicated by plant death or lack of seed germination, were made approximately 28 days after planting for each half of the column and averaged to obtain a single observation value. Experimental design was a randomized block design which was replicated three times. Data were analyzed as a factorial design, and the means were separated using a Waller-Duncan statistical test.

Herbicides used in the study had a wide range of physical and chemical properties that will affect their mobility in the soil (Table 4-3). The relative leaching potential index (RLPI) indicates the relative potential for the chemical to leach in the soil: the lower the number, the greater the potential to leach (Hornsby et al., 1991).

Table 4-3. Physical and chemical characteristics of herbicides.

Herbicide	Solubility in water at 25°C	Average partition coefficient (K_{oc})	Half-life in soil ($t_{1/2}$)	Relative leaching potential index[a] ($K_{oc}/ t_{1/2}$) x 10
	mg/L	mL/g	days	
bromacil	815	32	60	5
diuron	42	480	90	53
norflurazon	28	700	45-180	233
oryzalin	2.6	600	20	300
oxyfluorfen	0.1	100,000 (estimate)	35	>2000
simazine	6.2 @ 22°C	130	60	22
thiazopyr	2.5 @ 20°C	250[b]	64	39

Source: Ahrens, 1994

[a] Hornsby et al., 1991.

[b] McLaren, 1996.

Results and Discussion

Leaching of all herbicides increased as the amount of water applied increased from 1.25 to 5.0 inches (3.2 to 12.8 cm) (Table 4-4). This is presented graphically in Figure 4-2. When the data were analyzed, the interaction between herbicide leaching and water application rate was highly significant (Table 4-5). Results from both Tables 4-4 and 4-5 support the statement that increased water application rates significantly affect the movement of herbicides in the soil.

Table 4-4. Depth of control of bioindicator plants by herbicides in inches at various simulated rainfall rates.

Herbicide	Water application rate per acre			
	1.25"	2.5"	3.75"	5.0"
oryzalin	.75 m	1.42 m	1.63 m	1.63 m
thiazopyr	1.54 m	2.48 klm	2.75 klm	2.96 j-m
oxyfluorfen	2.13 lm	2.67 klm	3.17 j-m	3.50 j-m
diuron	3.29 j-m	4.50 i-l	5.17 ijk	6.34 i
norflurazon	4.41 i-l	7.17 hi	11.50 fg	15.84 e
simazine	5.58 ij	9.5 gh	13.83 ef	19.70 d
bromacil	13.67 ef	31.17 c	39.08 b	42.00 a

Means followed by same letter do not significantly differ (P=.05, Waller-Duncan k=100).

Based upon the findings of this study, the herbicides can be divided into three categories as evidenced by their movement in the soil as indicated by the death of the bioindicator plants: (1) low, (2) moderate, or (3) high mobility based on the results of the soil column method used in this study. Herbicides in the low mobility category are

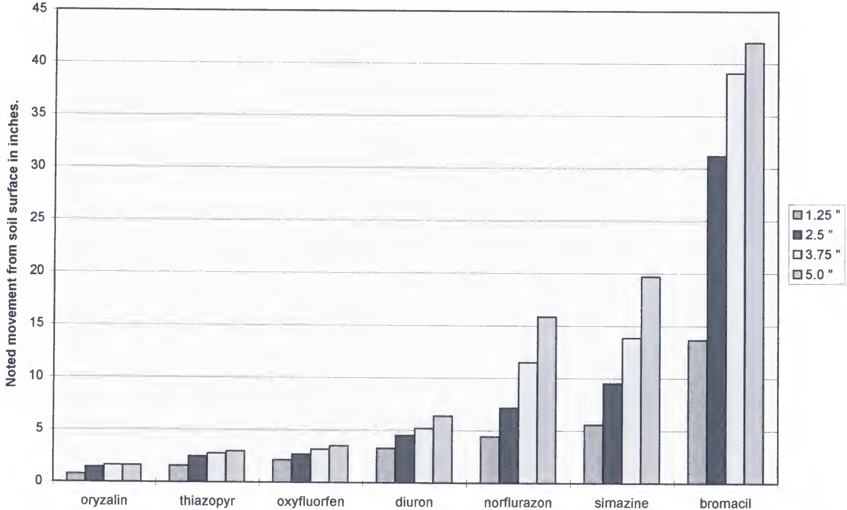

Figure 4-2. Herbicide mobility as observed using bioindicator plants in soil columns at four water application rates of 1.25, 2.5, 3.75 and 5.0 inches per acre.

Table 4-5. Complete factorial / Pooled Error ANOVA table.

Source	DF	Sum of Squares	Mean Square	F	Prob (F)
Replicate	2	1.1231	0.5616	0.153	0.8584
Herbicide	6	8101.4308	1350.2385	368.185	0.0001
Water Rates	3	921.8264	307.2755	83.788	0.0001
Herb*Water Rate interaction	18	1211.9457	67.3303	18.360	0.0001
Error	54	198.0331	3.3667		
Total	83	10434.3591			

oryzalin, thiazopyr, oxyfluorfen and diuron. Oryzalin moved from .75 to 1.63 inches (1.9 to 4.13 cm) as water application rates were increased from 1.25 to 5 inches (3.2 to 12.8 cm). Thiazopyr and oxyfluorfen was in between that of oryzalin and diuron. Diuron moved from 3.29 to 6.34 inches (8.3 to 16.09 cm) in the soil with 1.25 to 5 inches (3.2 to 12.8 cm) water, respectively. In this category of low mobility, some statistical differences did exist between oryzalin, the least mobile of the category, and diuron at the water application rates of 2.5, 3.75 and 5.0 inches (6.4, 9.6 and 12.8 cm); however, diuron was not different from thiazopyr and oxyfluorfen except at the 5 inch (12.8 cm) rate. The second category consisted of moderately mobile herbicides, norflurazon and simazine, which were not different statistically from one another except at the 5.0 inch (12.8 cm) application rate with simazine moving to a depth of 19.7 inches and norflurazon moving to a depth of 15.8 inches. The third category consisted of a highly mobile herbicide,

bromacil, which moved to a significantly greater depth than all other products at all water application rates ranging from 13.6 to 42 inches (34.7 to 106.7 cm) for the 1.25 to 5 inch rainfall rate, respectively. For all treated columns, only the top 42 inches were measured; however, bromacil movement was beyond 42 inches at the 5 inch application rate as the grass was dead below the 42-inch measurement point. The findings for bromacil were similar to information reported by Reddy and Singh (1993b) and Tan and Singh (1995). Estimated leaching of four herbicides in Candler fine sand (Alva & Singh, 1990) and in Astatula fine sand (Jain & Singh, 1992) provided a ranking of most mobile to least mobile in the order of bromacil, simazine, norflurazon, and diuron, respectively.

These data also correspond fairly well to the data published as to the organic carbon adsorption coefficient (K_{oc}) values shown in Table 4-3. The K_{oc} describes the relative affinity or attraction of the pesticide to the soil materials and, therefore, its mobility in the soil (Hornsby et al., 1991). Generally, as they contain more sand and less silt, clay, or organic matter, the soils will have a greater potential for leaching of herbicides, i.e., sands will have a greater potential to leach herbicides than will silt or loam soils. Pesticides that are very mobile have K_{oc} values less than 100 in sandy soils, or 50 in fine-textured soils, and should be used with caution due to leaching potential (Buttler et al., 1992). From the data in Table 4-3, the relative leaching potential index (RLPI) defines the relative dilution of the herbicide in soil solution or the reduction in mass as it moves through the soil and, therefore, its potential to leach into groundwater sources. The smaller the RLPI value, the greater the potential for the pesticide to leach. Ranking the

herbicides in this study from greatest to least potential to leach would be as follows: bromacil, simazine, thiazopyr, diuron, norflurazon, oryzalin, and oxyfluorfen.

Chemical Movement in Layered Soils Using Models

In recent years computer models have been used to predict the movement of chemicals in soils. One model which was developed by the University of Florida is "Chemical Movement in Layered Soils" (Nofziger & Hornsby, 1987). This program was written to serve as a management tool and decision aid. The Chemical Movement in Layered Soils (CMLS) model estimates the location of peak concentrations of nonpolar organic chemicals as they move through soils in response to downward movement of water.

When using CMLS model to predict the movement of herbicides in the soil differences between the computer model and the soil columns existed and is presented in Table 4-6. The soil used for estimating the herbicide movement is a Candler fine sand and can be found in the program data base as S53-22-(1-4). Bulk density and soil organic matter is similar to soil used in the soil column studies.

The estimate of water movement was added for the computer model to indicate at the 2.5-, 3.75-, and 5.0-inch application rate that water moved beyond the entire 48-inch length of the soil column.

In all cases, the soil column results indicated that the herbicides moved to a greater depth in the column at all water application rates than was predicted by CMLS model.

Table 4-6. Estimation of peak concentration and observed movement of herbicides in inches in response to downward movement of water using CMLS and soil columns.

Herbicide	Water application rate per acre (inches)							
	1.25"		2.5"		3.75"		5.0"	
	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed
oryzalin	0.2	0.75	0.4	1.42	0.5	1.63	0.7	1.63
thiazopyr	0.4	1.54	0.8	2.48	1.2	2.75	1.7	2.96
oxyfluorfen	0.0	2.13	0.0	2.67	0.0	3.17	0.0	3.50
diuron	0.2	3.29	0.4	4.50	0.7	5.17	0.9	6.34
norflurazon	0.2	4.41	0.3	7.17	0.5	11.50	0.6	15.84
simazine	0.8	5.58	1.6	9.50	2.3	13.83	3.1	19.70
bromacil *	2.8	13.67	5.5	31.17	21.2	38.08	38.9	42.00
Water	28.0		60.8		86.5		111.8	

* bromacil was measured to a depth of 42 inches; however, movement was below that depth.

Differences between the two may be attributed to the following: (1)The computer model is making predictions based upon a natural soil profile, whereas the soil column has been hand packed, thus making the soils different in soil profile, compaction, and composition. Differences between soil column and CMLS data may be less if this study had used a natural soil column which did not disturb or mix the soil profile; however, to collect columns to a depth of 48 inches in a natural state would be extremely difficult. (2) The model is predicting the peak concentration of the herbicide, whereas the bioindicator plants indicate where toxic levels of the herbicide exists, to the plant species used. Toxic levels of herbicides should be found above and below the peak concentration, and these levels could still be toxic to the chosen bioindicator plants. Peak concentration and the

presence of the herbicide are two different concepts. (3) The model is making predictions based upon the average K_{oc} for the selected herbicide. Herbicides will have a range of K_{oc} values for based upon the different soil types. As an example, oryzalin has a published average K_{oc} of 600 but ranges from 93 to 2700 mL/g (Ahrens, 1994) depending on soil type. When you change the K_{oc} value from 600 to 93 or 2700, the predicted movement of the herbicide is profoundly changed (Table 4-7). The lower K_{oc} value of 93 indicates movement of the herbicide 5 to 6 times further than the average K_{oc} value of 600 and 21 to 31 times further when comparisons are made for a K_{oc} value of 2700. Additionally, when the label for oxyfluorfen is examined, a statement about the need for at least one-quarter inch of irrigation or rainfall should occur within three to four weeks can be found. However, when a K_{oc} value of 100,000 is used (Table 4-6), the model predicts that oxyfluorfen did not move from the soil surface even at 5 inches of applied water. If this predicted movement of 0.0 inches was correct, then the herbicide would offer little herbicidal properties and be broken down by light and other factors, thus reducing effectiveness of oxyfluorfen.

Since the program uses the average K_{oc} and not a specific value for the given soil type, the use of the model could incorrectly predict the herbicide movement for a specific soil in which the K_{oc} is different than the average K_{oc} value. However, the model does provide a quick method to compare different potential movements of herbicides using average K_{oc} values. If specific estimates of herbicide movement are needed, K_{oc} values

should be obtained for the soil in question and reliance based upon average values should be avoided.

Table 4-7. Effect of changing K_{oc} values on the movement of oryzalin in Candler fine sand.

Rainfall rates	K_{oc} value		
	93	600	2700
	predicted movement in inches		
1.25"	1.1	0.2	0.0
2.5"	2.1	0.4	0.1
3.75"	3.2	0.5	0.1
5.0"	4.3	0.7	0.2

Conclusions

The herbicides in this study can be divided into three basic categories of low, moderate, or high mobility based upon their movement in the soil columns. Low mobility herbicides were oryzalin, thiazopyr, oxyfluorfen, and diuron which moved in the soil from .75 inch to 6.34 inches at 1.25 to 5 inches, respectively, for oryzalin and diuron. Moderately mobile herbicides were norflurazon and simazine and moved to a depth of 4.41 inches for norflurazon at 1.25 inches and 19.7 inches for simazine at 5.0 inches. Bromacil was the most mobile herbicide in the study at all water application rates and moved beyond a depth of 42 inches when 5 inches of water was applied. Similar findings

for the movement of bromacil were also reported by Reddy and Singh (1993b) and Tan and Singh (1995).

Ranking herbicides based upon mobility in the soil columns in the order of least mobile to greatest would be as follows: oryzalin, thiazopyr, oxyfluorfen, diuron norflurazon, simazine, and bromacil with the ranking of diuron, norflurazon, simazine, and bromacil being in the same order as published by Jain and Singh (1992).

Citrus growers should be aware of the leaching potential of herbicides and select those herbicides that will minimize potential groundwater contamination problems, especially if the grove contains soils that are sandy and have low organic matter.

When using computer models to estimate herbicide movement for a specific soil, an understanding of input parameters should be clearly understood. As with the CMLS program, adjusting the K_{oc} value from the average to a specific K_{oc} for the soil can profoundly change the predicted movement. Computer models do offer a quick way to estimate and compare mobility of different herbicide products using the same conditions; however, caution should be used in making statements about how this predicted mobility would occur in a field situation unless the program uses specific K_{oc} for the soil type under study.

CHAPTER 5
WEED CONTROL FIELD STUDIES

Successful weed management is the control or suppression of unwanted weed species to a level that does not cause economic damage to the citrus tree or fruit crop or impede production or harvesting operations. Complete, year-round prevention of all weed species from the herbicide-treated area is economically unwarranted and horticulturally unnecessary. Weed control is an important citrus production operation that accounts for approximately 24% of the annual total specified production cost in Central Florida citrus (Muraro & Oswalt, 1996). Herbicides are applied to control unwanted weed growth, thereby reducing or eliminating weed competition with the citrus tree for nutrients, water and space (Singh et al., 1990). Weed control also facilitates production and harvesting operations. Preemergence herbicides can be used individually, with other preemergence herbicides to broaden weed control spectrum, or in combination with postemergence herbicides to control established weeds. The advantages and benefits of weed control are discussed in Chapter 2.

To study weed control in Florida citrus, using preemergence herbicides, a series of field studies were developed to examine the effectiveness of seven herbicides used individually or in combination to broaden the weed control spectrum. The field studies were conducted over a two-year period with preemergence herbicides being applied every

120 days. Visual observations as to the percent weed control were made at 30 day intervals with the first rating 30 days after treatment (DAT) for four months or 120 DAT and prior to the next herbicide application.

The objectives of the field studies were to examine the effectiveness of low rates of the various preemergence herbicide treatments at typical grove sites of the Central Florida Ridge, East Coast, and Flatwoods citrus production regions and to determine if differences in percent weed control affected tree growth. The three sites were Lake Garfield, Indiantown, and Arcadia (Figure 5-1).

Materials and Methods

Three young groves planted in 1994 or 1995 located in Lake Garfield (Polk County), Indiantown (Martin County), and Arcadia (DeSoto County) were selected in the spring of 1995 as locations for the two-year herbicide trials. These three sites are representative of the state's major citrus production regions. All study sites have low volume microsprinkler irrigation systems. The soil type as classified by county soil survey guides issued by the United State Department of Agriculture for each site (Cowherd et al. 1989, McCollum & Cruz, 1981, Ford et al., 1990) are shown in Table 5-1. Actual soil will differ from the soil classification as reported for Indiantown and Arcadia due to site drainage improvements that resulted from the construction of raised beds in which the citrus trees are planted. During the bedding process, some of the soil from the lower soil profile to a depth of approximately two feet is rolled on top of the original soil surface by road graders to form a raised bed. This bedding process is

Figure 5-1. Location of herbicide field studies.

designed to improve both surface and subsurface drainage and results in a mixed soil profile.

Table 5-1. Classification of soils in experimental sites.

Location	Soil name	Family or higher taxonomic class
Lake Garfield	Candler sand	Hyperthermic, uncoated Typic Quartzipsamments
Indiantown	Wabasso fine sand	Sandy, siliceous, hyperthermic Alfic Haplaquods
Arcadia	Malabar fine sand	Loamy, siliceous, hyperthermic Grossarenic Ochraqualfs
	and Farmton	Sandy, siliceous, hyperthermic Arenic Ultic Haplaquods

The grove operators controlled and applied all horticultural production practices (water, fertilizer, and spray) with the exception of herbicide during the two years of the study. Specific site information is contained in Table 5-2.

Rainfall for the three sites for each rating period is listed in Table 5-3 and was provided from grower records from rain gauges located near the test sites. Rainfall totals are inclusive from herbicide application until the next herbicide application date. The rainfall during the first rating period was extremely heavy at both Indiantown and Arcadia, totaling 64.8 and 39.3 inches, respectively. Heavy rainfall during the period could have easily affected the weed control effectiveness due to leaching of herbicides beyond the zone of weed seed germination.

Table 5-2. Grove site information.

	Site		
	Lake Garfield	Indiantown	Arcadia
Variety	Red Navel	Valencia	Valencia
Rootstock	Swingle citrumelo	Swingle citrumelo	Swingle citrumelo
Date planted	June 1994	April 1995	July 1994
Tree spacing	10 feet x 25 feet, flat planting (no beds)	9 feet x 25 feet, double row bed	12.5 feet x 25 feet, single row bed
Trees per plot	5	5	5
Plot length	50 feet	45 feet	62.5 feet
Average soil pH (0 to 6 inches)	6.6	6.1	5.5
Average soil organic matter	0.94 %	1.08 %	1.4 %
Treatment dates:			
First year	May 15, 1995 September 20, 1995 February 9, 1996	June 8, 1995 November 17, 1995 March 22, 1996	June 1, 1995 November 14, 1995 April 16, 1996
Second year	June 20, 1996 December 23, 1996 April 25, 1997	July 17, 1996 December 2, 1996 March 24, 1997	September 5, 1996 January 30, 1997 May 27, 1997

Table 5-3. Rainfall for each 120-day rating period during the 2-year study.

Location	Rainfall per rating period (in inches)					
	First	Second	Third	Fourth	Fifth	Sixth
Lake Garfield	25.1	15.8	15.5	25.4	12.6	20.4
Indiantown	64.8	11.8	31.7	32.0	8.2	35.6
Arcadia	39.3	9.0	22.7	16.6	14.1	16.2

Major Weeds Species at the Three Sites

Major weed species present at each site were noted during the two-year study (Table 5-4). At Lake Garfield broadleaf species such as Florida and Brazil pusley were the most difficult to control, whereas Indiantown and Arcadia generally contained more than just broadleaf weed species.

Weed Control

All treatments were applied to five tree plots and were replicated five times at each site using a randomized complete block design. Plots were visually rated as to the percent weed control, using a rating scale of 0 to 100, with 0 being ground completely covered with weeds and 100 being complete weed control. Observations were made every 30, 60, 90, and 120 days after treatment (DAT) for all plots during the two-year study period. Ratings for 120 DAT for the first rating period at Indiantown and Arcadia were omitted due to poor weed control at 90 DAT. Average ratings for the five plots for each treatment period at 30-day interval is provided in the Appendix. Data were analyzed using a Waller-Duncan means separation test at a significance level of 5%.

Herbicides were applied approximately every 120 days from a tractor-mounted boom-sprayer equipped with five stainless-steel airtight tanks using compressed air. Application volume was 30 gallons per acre (GPA) applied at 30 pounds per square inch (PSI) using 8002 Teejet nozzle tips in the boom with an offset OC-04 nozzle at the end of the boom. Tractor speed was 2.78 miles per hour (MPH). Total treated width ranged

Table 5-4. Major weed species present at each site.

Common name	Scientific name	Lake Garfield	Indiantown	Arcadia
alexandergrass	*Brachiaria plantaginea*	x	x	x
American black nightshade	*Solanum americanum*		x	x
annual sedge	*Cyperus compressus*		x	x
balsam apple	*Momordica charantia*		x	x
bermudagrass	*Cynodon dactylon*		x	x
Brazil pusley	*Richardia brasiliensis*	x		x
Carolina geranium	*Geranium carolinianum*		x	x
carpetweed	*Mollugo verticillata*	x	x	x
chickweed	*Stellaria media*	x	x	x
citron melon	*Citrullus vulgaris*	x		
crabgrass	*Digitaria spp.*	x	x	x
crowfootgrass	*Dactyloctenium aegyptium*	x	x	x
cudweed	*Gnaphalium pensylvanicum*	x	x	x
cutleaf evening primrose	*Ocnothera laciniata*		x	x
cutleaf ground-cherry	*Physalis angulata*		x	x
dayflower	*Commelina communis*	x	x	x
doveweed	*Murdannia nudiflora*		x	x
Florida beggarweed	*Desmodium tortuosum*	x	x	x
Florida pusley	*Richardia scabra*	x		x
goatweed	*Scoparia dulcis*		x	x
goosegrass	*Eleusine indica*	x	x	x
guineagrass	*Panicum maximum*	x	x	x
hairy beggartick	*Bidens pilosa*	x	x	x
hairy indigo	*Indigofera hirsuta*	x	x	x

Table 5-4--continued.

Common name	Scientific name	Lake Garfield	Indiantown	Arcadia
lambsquarter	*Chenopodium album*	x	x	x
morningglory	*Ipomoea spp.*	x		
natalgrass	*Rhynchelytrum repens*		x	x
oldfield toadflax	*Linaria canadensis*	x		
phasey bean	*Macroptilium lathyroides*		x	x
pigweed	*Amaranthus spp.*	x	x	x
primrose willow	*Ludwigia octovalvis*		x	x
purple nutsedge	*Cyperus rotundus*	x	x	x
ragweed	*Ambrosia artemisiifolia*	x	x	x
red spiderling	*Boerhavia diffusa*		x	x
red tassel flower	*Emilia fosbergii*		x	x
sandspur	*Cenchrus spp.*	x	x	x
sicklepod	*Casia obtusifolia*	x		
signalgrass	*Brachiaria platyphylla*	x	x	x
smutgrass	*Sporobolus poiretii*			x
spurge	*Euphorbia spp.*	x	x	x
torpedograss	*Panicum repens*		x	x
Virginia pepperweed	*Lepidium virginicum*	x	x	x
wandering Jew	*Tradesscantia albiflora*	x	x	x
yellow nutsedge	*Cyperus ensclentus*	x	x	x

from 10 to 14 feet in the tree row. Some treatment dates exceeded the 120-day period due to production operations, weather conditions, and/or scheduling conflicts.

Herbicide treatments evaluated in the study are listed in Table 5-5. The treatment rates per acre at all three sites were the same during the first year and remained at the first year rate during both years at Lake Garfield. The herbicide rates were increased during the second year at Indiantown and Arcadia (Table 5-5) due to unacceptable weed control results at the first year rates.

All herbicide applications were made to ground that did not have large amounts of exposed grasses or broadleaf weeds. In cases where weed growth was excessive, as in many of the plots at Indiantown and Arcadia, the plots were treated with glyphosate at rates ranging from 2 to 3 lb ai/A prior to the application of the preemergence herbicides to control existing vegetation. Efforts were conducted to make sure the plots were free of living weeds prior to the application of the preemergence herbicides to confirm that any weeds present in the plots during the rating intervals had germinated after the application of the preemergence herbicides. Some plots did not require postemergence applications of glyphosate, but for consistency, glyphosate was applied to all plots at all locations.

Tree Growth Responses to Herbicide and Weed Competition

It has been reported that weed competition reduces the growth of citrus trees (Ryan & Kretchman, 1968; Jordan, 1981; Jordan et al., 1992) and other tree crops (Foshee et al., 1997; Merwin & Ray, 1997). To confirm the effect that weed competition had on the growth of citrus trees, three trees from each treatment plot were

Table 5-5. Preemergence herbicide and rate used in study during first and second years.

		Per application rates (lb ai/A)	
Chemical name	Trade name	First year*	Second year
bromacil	Hyvar 80WP	1.6	2.13
diuron	Direx 80DF	1.6	2.13
bromacil + diuron	Hyvar 80WP + Direx 80DF	1.6 + 1.6	2.13 + 2.13
diuron + oryzalin	Direx 80DF + Surflan 80DF	1.6 + 1.6	2.6 + 2.0
diuron + thiazopyr	Direx 80DF + Mandate 2E	1.6 + 0.25	2.13 + 0.38
diuron + thiazopyr	Direx 80DF + Mandate 2E	1.6 + 0.33	2.13 + 0.49
norflurazon	Solicam 80DF	1.6	2.4
norflurazon + diuron	Direx 80DF + Solicam 80DF	1.6 + 1.6	2.13 + 2.4
norflurazon + simazine	Solicam 80DF + Princep-Caliber 90DF	1.6 + 1.8	2.4 + 2.64
norflurazon + oxyfluorfen	Solicam 80DF + Goal 1.6E	1.6 + 0.8	2.4 + 1.2
oryzalin	Surflan 80DF	1.6	2.0
oxyfluorfen	Goal 1.6E	0.8	1.2
oxyfluorfen + thiazopyr	Goal 1.6E + Mandate 2E	0.8 + 0.25	1.2 + 0.38
oxyfluorfen + thiazopyr	Goal 1.6E + Mandate 2E	0.8 +0.33	1.2 + 0.49
simazine	Princep-Caliber 90DF	1.8	2.64
simazine + oryzalin	Princep-Caliber 90DF + Surflan 80DF	1.8 + 1.6	2.64 + 2.0
simazine + thiazopyr	Princep-Caliber 90DF + Mandate 2E	1.8 + 0.25	2.64 + 0.38
simazine + thiazopyr	Princep-Caliber 90DF + Mandate 2E	1.8 + 0.33	2.64 + 0.49
thiazopyr	Mandate 2E	0.25	0.375
thiazopyr	Mandate 2E	0.33	0.49
control	(Roundup only)	0.0	0.0

*Rates at Lake Garfield remained the same in the second year of the study.
All plots received roundup to remove live vegetation.

systematically measured during the study. Canopy volume was calculated from measurements for the north-south width, east-west width, and the height of the trees. Trunk cross-sectional diameter of the tree were measured at 2.5 inches above the bud union of the selected trees within each plot. Data were recorded at the beginning of the study and at the end of the first and second years.

Results and Discussion

All preemergence herbicide treatments provided significantly greater weed control than did untreated controls at all three locations (Table 5-6, 5-7, and 5-8). During the first year, treatment rankings based on overall mean weed control showed the best treatments at all locations were combinations that included norflurazon or bromacil, which is similar to the findings reported by Singh et al. (1990). Percent weed control was generally the highest at Lake Garfield, lower at Indiantown, and lowest at Arcadia for most herbicides. Poor weed control during the first year at Indiantown and Arcadia indicated rates were too low to provide acceptable weed control, thus the rates were increased to the maximum herbicide rate per acre or by 50% as indicated in Table 5-5. Rainfall at Indiantown and Arcadia were extremely heavy during the first rating period (Table 5-3) possibly reducing the herbicide concentration in the zone of seed germination due to leaching of herbicides in the soil. Ratings at 120 DAT, which are less than 80% weed control in most cases, would be considered unacceptable by many growers. For these studies weed control of 80% of the weeds or greater at 120 DAT was required to consider any given treatment as

Table 5-6. Preemergence herbicide treatments and weed control (%) at Lake Garfield for two years.

Herbicide	Rate First Year (lb ai/A)	% Weed Control Ratings				Rate Second Year (lb ai/A)	% Weed Control Ratings			
		First 120 DAT	Second 120 DAT	Third 120 DAT	Average First Year		Fourth 120 DAT	Fifth 120 DAT	Sixth 120 DAT	Average Second Year
bromacil	1.6	92 a	88 a-d	94 a	91 a	1.6	80 ab	94 a	87 abc	87 a
diuron	1.6	81 abc	86 bcd	56 efg	74 bcd	1.6	64 c-f	85 cde	64 f-i	71 cd
bromacil + diuron	1.6 + 1.6	90 ab	90 ab	94 a	92 a	1.6 + 1.6	81 a	95 a	86 a-d	87 a
diuron + oryzalin	1.6 + 1.6	74 b-e	88 a-d	74 bc	79 bc	1.6 + 1.6	68 a-f	90 a-d	75 a-h	77 a-d
diuron + thiazopyr	1.6 + 0.25	67 c-f	87 a-d	67 b-f	74 b-e	1.6 + 0.25	64 b-f	87 b-e	81 a-f	77 a-d
diuron + thiazopyr	1.6 + 0.33	68 c-f	86 a-d	74 bc	76 bcd	1.6 + 0.33	68 a-f	88 a-e	78 a-h	78 a-d
norflurazon	1.6	57 d-g	87 a-d	66 c-f	70 b-e	1.6	69 a-f	86 b-e	82 a-e	79 a-d
norflurazon + diuron	1.6 + 1.6	73 b-e	89 abc	81 b	81 b	1.6 + 1.6	79 abc	92 ab	88 ab	87 a
norflurazon + simazine	1.6 + 1.8	60 c-g	90 ab	70 b-e	73 b-e	1.6 + 1.8	74 a-e	91 abc	87 abc	84 ab
norflurazon + oxyfluorfen	1.6 + 0.8	78 a-d	92 a	73 bcd	81 b	1.6 + 0.8	78 a-d	91 abc	89 a	86 a
oryzalin	1.6	48 fg	86 bcd	59 c-g	64 def	1.6	62 def	87 b-e	66 e-i	71 cd
oxyfluorfen	0.8	65 c-f	91 ab	51 fg	69 cde	0.8	63 c-f	80 efg	79 a-g	74 bcd
oxyfluorfen + thiazopyr	0.8 + 0.25	81 abc	91 ab	57 d-g	76 bcd	0.8 + 0.25	70 a-f	87 b-e	73 b-h	77 a-d
oxyfluorfen + thiazopyr	0.8 + 0.33	82 abc	91 ab	61 c-g	78 bc	0.8 + 0.33	73 a-e	89 a-d	82 a-e	81 abc
simazine	1.8	38 gh	83 cd	33 h	53 f	1.8	30 hi	73 gh	30 j	45 fg
simazine + oryzalin	1.8 + 1.6	61 c-g	89 a-d	73 bcd	75 bcd	1.8 + 1.6	60 ef	88 a-e	62 ghi	70 cde
simazine + thiazopyr	1.8 + 0.25	66 c-f	86 bcd	54 efg	69 cde	1.8 + 0.25	61 ef	83 def	72 c-h	72 cd
simazine + thiazopyr	1.8 + 0.33	66 c-f	87 a-d	63 c-g	72 b-e	1.8 + 0.33	55 fg	87 b-e	70 d-i	71 cd
thiazopyr	0.25	54 efg	82 d	48 gh	62 ef	0.25	42 gh	75 fgh	52 i	57 ef
thiazopyr	0.33	69 c-f	86 bcd	48 gh	68 cde	0.33	59 efg	83 def	60 hi	67 de
control	0.0	23 h	74 e	17 i	39 g	0.0	22 i	67 h	18 j	38 g

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan). Above means were transformed using arcsin square root percent and are reported in de-transformed units.

Table 5-7. Preemergence herbicide treatments and weed control (%) at Indiantown for two years.

Herbicide	Rate First Year (lb ai/A)	% Weed Control Ratings				Rate Second Year (lb ai/A)	% Weed Control Ratings			
		First 90 DAT	Second 120 DAT	Third 120 DAT	Average First Year		Fourth 120 DAT	Fifth 120 DAT	Sixth 120 DAT	Average Second Year
bromacil	1.6	20 cde	84 b-f	8 e-h	35 def	2.13	77 ab	92 a-d	74 bc	81 b
diuron	1.6	16 cde	74 e-i	2 ghi	28 fg	2.13	62 bcd	73 hij	39 d-h	59 cde
bromacil + diuron	1.6 + 1.6	22 bcd	95 a	19 cd	46 bc	2.13 + 2.13	88 a	97 ab	88 ab	91 a
diuron + oryzalin	1.6 + 1.6	19 cde	76 d-i	6 e-i	33 def	2.6 + 2.0	50 de	83 e-h	53 d	63 cd
diuron + thiazopyr	1.6 + 0.25	19 cde	79 c-h	6 e-i	33 def	2.13 + 0.38	62 bcd	74 g-j	45 def	60 cd
diuron + thiazopyr	1.6 + 0.33	19 cde	78 c-h	7 e-h	33 def	2.13 + 0.49	57 cd	86 c-f	54 cd	66 c
norflurazon	1.6	24 a-d	71 f-i	13 cde	33 def	2.4	76 abc	91 b-e	75 b	81 b
norflurazon + diuron	1.6 + 1.6	33 ab	92 ab	40 a	56 a	2.13 + 2.4	89 a	97 ab	91 a	92 a
norflurazon + simazine	1.6 + 1.8	27 abc	90 abc	21 bc	46 bc	2.4 + 2.64	86 a	98 a	85 ab	89 ab
norflurazon + oxyfluorfen	1.6 + 0.8	35 a	87 a-d	34 ab	52 ab	2.4 + 1.2	88 a	94 abc	84 ab	88 ab
oryzalin	1.6	16 de	49 j	4 e-i	24 g	2.0	25 gh	61 j	24 g-j	37 hi
oxyfluorfen	0.8	18 cde	82 b-g	3 f-i	34 def	1.2	49 def	81 f-i	31 r-i	55 c-g
oxyfluorfen + thiazopyr	0.8 + 0.25	22 cd	71 f-i	11 c-f	35 def	1.2 + 0.38	57 bcd	83 e-h	52 de	64 cd
oxyfluorfen + thiazopyr	0.8 + 0.33	24 a-d	79 c-h	19 cd	40 cd	1.2 + 0.49	52 de	81 f-i	48 def	61 cd
simazine	1.8	16 de	68 hi	2 hi	28 fg	2.64	45 d-g	69 j	21 hij	47 e-h
simazine + oryzalin	1.8 + 1.6	17 cde	87 a-e	4 f-i	36 def	2.64 + 2.0	63 bcd	88 c-f	17 ij	57 c-f
simazine + thiazopyr	1.8 + 0.25	19 cde	86 b-e	11 c-f	39 cd	2.64 + 0.38	57 bcd	87 c-f	47 def	64 cd
simazine + thiazopyr	1.8 + 0.33	25 a-d	79 c-h	11 c-f	38 cde	2.64 + 0.49	34 e-h	84 d-g	41 d-g	53 d-g
thiazopyr	0.25	21 cde	62 ij	7 e-h	30 efg	0.375	27 gh	69 j	38 d-h	46 fgh
thiazopyr	0.33	22 bcd	71 ghi	9 d-g	34 def	0.49	24 h	70 ij	31 f-i	42 gh
control	0.0	12 e	32 k	1 i	14 h	0.0	28 fgh	44 k	13 j	29 i

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan). Above means were transformed using arcsin square root percent and are reported in de-transformed units.

Table 5-8. Preemergence herbicide treatments and weed control (%) at Arcadia for two years.

Herbicide	Rate First Year (lb ai/A)	% Weed Control Ratings				Rate Second Year (lb ai/A)	% Weed Control Ratings			
		First 90 DAT	Second 120 DAT	Third 120 DAT	Average First Year		Fourth 120 DAT	Fifth 120 DAT	Sixth 120 DAT	Average Second Year
bromacil	1.6	14 a	77 a	39 b	44 a	2.13	27 bcd	62 d-g	61 c	50 c
diuron	1.6	14 a	36 bc	18 def	22 bc	2.13	15 def	40 h	15 def	24 fg
bromacil + diuron	1.6 + 1.6	11 abc	82 a	55 a	49 a	2.13 + 2.13	40 bc	88 a	87 a	72 ab
diuron + oryzalin	1.6 + 1.6	7 a-d	25 c-f	13 efg	15 c-g	2.6 + 2.0	23 cde	76 a-d	22 de	42 cd
diuron + thiazopyr	1.6 + 0.25	7 a-d	13 efg	19 cde	14 d-g	2.13 + 0.38	11 ef	66 c-f	18 def	32 d-g
diuron + thiazopyr	1.6 + 0.33	4 bcd	21 c-g	12 efg	12 efg	2.13 + 0.49	9 f	65 c-g	24 d	33 d-g
norflurazon	1.6	6 a-d	11 fg	15 efg	11 efg	2.4	41 bc	78 a-d	71 bc	63 b
norflurazon + diuron	1.6 + 1.6	12 ab	20 c-g	17 def	17 c-f	2.13 + 2.4	44 b	79 abc	72 bc	65 b
norflurazon + simazine	1.6 + 1.8	12 ab	44 b	27 bcd	27 b	2.4 + 2.64	65 a	83 ab	83 ab	77 a
norflurazon + oxyfluorfen	1.6 + 0.8	12 ab	21 c-g	31 bc	22 bcd	2.4 + 1.2	69 a	83 ab	80 ab	77 a
oryzalin	1.6	8 abc	10 gh	8 gh	9 g	2.0	9 f	50 fgh	13 def	24 fg
oxyfluorfen	0.8	3 cd	15 efg	9 fgh	9 g	1.2	28 bcd	46 gh	8 fg	27 efg
oxyfluorfen + thiazopyr	0.8 + 0.25	3 cd	19 d-g	12 efg	11 efg	1.2 + 0.38	45 b	52 e-h	12 ef	37 de
oxyfluorfen + thiazopyr	0.8 + 0.33	3 cd	14 efg	13 efg	10 fg	1.2 + 0.49	25 cde	69 b-e	13 def	36 def
simazine	1.8	2 d	23 c-g	3 hi	9 g	2.64	6 f	13 i	3 g	8 h
simazine + oryzalin	1.8 + 1.6	5 a-d	26 cde	12 efg	14 c-g	2.64 + 2.0	6 f	49 fgh	13 def	22 g
simazine + thiazopyr	1.8 + 0.25	2 d	20 c-g	11 efg	11 efg	2.64 + 0.38	7 f	71 bcd	17 def	31 d-g
simazine + thiazopyr	1.8 + 0.33	8 abc	35 bcd	12 efg	18 cde	2.64 + 0.49	8 f	75 a-d	25 d	37 de
thiazopyr	0.25	9 abc	11 fgh	12 efg	11 efg	0.375	15 def	61 d-g	16 def	31 d-g
thiazopyr	0.33	11 abc	10 gh	12 efg	10 g	0.49	9 f	74 a-d	20 de	34 def
control	0.0	3 cd	2 h	2 i	2 h	0.0	7 f	4 i	2 g	4 h

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan). Above means were transformed using arcsin square root percent and are reported in de-transformed units.

providing successful weed control. The 80% weed control requirement was also used by Singh et al. (1990) as a threshold to judge successful weed control at 120 DAT.

At Lake Garfield (Table 5-6), the 120 DAT ratings were generally higher during the winter months (second and fifth rating periods) as less weed growth occurred during this time than during the first, third, fourth, and six application rating periods. Rating data for the 30, 60, 90, and 120 DAT for all six treatment periods is provided in Tables A-1 through A-6 in the Appendix. Frost and freezing temperatures did occur during the winters of 1995-1996 and 1996-1997, which killed or damaged cold-sensitive annual weeds present at this site. Over the two-year period, both Florida and Brazil pusley (*Richardia scabra* and *Richardia brasiliensis*) became the dominant weed species in most plots. Those herbicides, at the application rates used, that offer poor pusley control resulted in lower weed control rating values. Treatments containing bromacil provided the greatest level of weed control during both years and were statistically different from all other treatments during the first year; however, bromacil is not currently registered for use in sandy, vulnerable ridge-type soils due to groundwater contamination problems. Since bromacil provided 90% and 87% weed control during the first and second years, respectively, the herbicide manufacturer should consider options to modify product use conditions to allow for its re-registration for use in Ridge. These modifications could include low rates or allow for bromacil applications only during specific months, excluding months with heavy rainfall (May-September). Of the products legal for use on the Ridge, those that provided average yearly weed control greater than 80% during the first year were combinations of norflurazon + oxyfluorfen (81%) and norflurazon +

diuron (81%). During the second year, the same two herbicide combination (norflurazon + oxyfluorfen, 86%, and norflurazon + diuron, 87%), as well as norflurazon + simazine (84%) and oxyfluorfen + thiazopyr (81%), provided average annual weed control in excess of 80%; however, all of these products had weed control ratings below 80% during the fourth treatment period. Oxyfluorfen at the present time does not have a label that permits its use on bearing citrus trees, so it should only be used in nonbearing grove situations. When comparisons are made between the first and second year average annual ratings, norflurazon's rating improved during the second year over the first. Individual herbicide products that offer weed control mainly for grasses (thiazopyr, oryzalin, oxyfluorfen) or broadleaf weeds (diuron, simazine) should be used in combination with other products to broaden control spectrum of both grasses and broadleaf species, because the weed control rating for the above products at this site was generally in the 50 to 60% range. In several cases, the use of two herbicide products (diuron + thiazopyr, diuron + oryzalin, simazine + oryzalin, simazine + thiazopyr oxyfluorfen + thiazopyr) did not achieve annual ratings of greater than 80% weed control. If these herbicide combinations are to be used successfully, the rates should be increased, if the label permits, to provide a higher level of weed control, especially during the spring and summer months.

At Indiantown (Table 5-7), on an annual basis, all products, at the rates used, provided unacceptable weed control during the first year, ranging from 20 to 50%. Some products did provide acceptable weed control during the winter rating period; however, weed control during the remaining eight months of the year was clearly unacceptable.

Thus, the rates for all herbicide combinations were increased during the second year of the study (Table 5-5). During the first rating period, the 120 DAT rating was omitted due to very poor weed control at the 90 DAT rating. Rating data for 30, 60, 90 and 120 DAT for all six rating periods (except where noted) are provided in Tables A-7 through A-12 in the Appendix. When the herbicide application rates were increased, the weed control rating for all herbicide treatments increased during the second year of the study compared to the first year. Several treatments did provide greater than 80% weed control for all rating periods during the second year. During the second year norflurazon + diuron (92%), bromacil + diuron (91%), norflurazon + simazine (89%), and norflurazon + oxyfluorfen (88%) all provided weed control on an annual basis at greater than 80% as well as greater than 80% at each rating period. Bromacil and norflurazon, when used individually, provided greater than 80% weed control on an annual basis; however, they did fall below 80% weed control during one or more rating periods. Products that offer weed control mainly for grasses (thiazopyr, oryzalin, oxyfluorfen) or broadleaf weeds (simazine) should be used in combination with other products to broaden the control spectrum. In several cases, the use of two herbicide products (diuron + oryzalin, diuron + thiazopyr, oxyfluorfen + thiazopyr and simazine + thiazopyr) did not achieve annual ratings of greater than 80% weed control. If these herbicide combinations are to be used successfully, the rates should be increased (within label limits) to provide a higher level of weed control especially during the spring and summer months.

At Arcadia (Table 5-8), the control of weeds on an annual basis during both years was lower than the weed control achieved at Indiantown and much lower than at Lake

Garfield. The 120 DAT weed control ratings during the first treatment period were omitted due to extremely poor weed control at 90 DAT. Rating data for 30, 60, 90, and 120 DAT for all six rating periods (except where noted) is provide in Tables A-13 through A-18 in the Appendix. During the first year all herbicides, at the rates used, provided unacceptable weed control with only bromacil + diuron reaching greater than 80% during the winter rating period of 1995-1996. No products achieved 80% weed control on an annual basis during the first year, thus the herbicide rates were increased similarly to Indiantown (Table 5-5). When the herbicide rates were increased, the weed control rating for almost all herbicides and herbicide combinations increased during the second year of the study compared to the first year (Table 5-8). During the second year (at higher herbicide rates) no products averaged greater than 80% weed control on an annual basis. Weed control ratings for Arcadia (Table 5-8) were lower than Indiantown (Table 5-7). Ratings for the fourth period were also lower than expected, especially after increasing the herbicide rates. It is speculated that part of the lower rating during the fourth period may be attributed to the poor weed control in previous rating periods, which allowed increased numbers of seeds to be deposited in the plots, making it more difficult to achieve successful weed control later. During the fifth and sixth rating periods, bromacil + diuron (88%, 87%), norflurazon + simazine (83%, 83%), and norflurazon + oxyfluorfen (83%, 80%) did achieve greater than 80% weed control during those two periods. Weed control did improve for most herbicide products by the fifth and sixth rating periods compared to the fourth period. Weed growth was extremely vigorous at this site, as indicated by the control rating of 7%, 4%, and 2% during the fourth, fifth, and

sixth rating periods, respectively. Products that offered mainly grass or broadleaf control were not successful in reducing weed growth, especially during the spring through fall rating periods. Even when some of those products were mixed together, weed control on an annual basis was still far below the 80% weed control targets.

Table 5-9 ranks the herbicide treatment at each of the three locations with 1 representing the best weed control for the first year of the study. Overall weed control was highest at Lake Garfield and lowest at Arcadia. Indiantown's ratings were slightly higher than Arcadia's but still much lower than Lake Garfield's. These ratings are reflective of the greater weed vigor at Arcadia compared to Indiantown and Lake Garfield. The bromacil + diuron and norflurazon +oxyfluorfen, norflurazon + diuron or norflurazon + simazine combination provided the greatest level of control; however, the control levels at Indiantown and Arcadia were still well below what growers would expect from a successful weed control program.

Table 5-10 ranks the individual ratings at the three sites during the second year of the study. Since herbicide rates at all three sites were not the same, an annual rating of the three locations was not calculated. Generally, the treatment combinations that included norflurazon or bromacil provided the highest level of weed control at all three sites.

Herbicide Effect on Tree Growth

From each of the three sites, tree canopy volume and trunk cross-sectional diameter were measured at the beginning of the experiment, at the end of the first year and at the conclusion of the experiment. Data for Indiantown are not reported due to damage

Table 5-9. Average weed control ranking and average weed control (%) for three sites during the first year where the herbicide use rate was applied at the same application rate.

Herbicide	Rate First Year (lb ai/A)	Ranking based upon % weed control			Average weed control (%)				Ranking for three sites
		Lake Garfield	Indiantown	Arcadia	Lake Garfield	Indiantown	Arcadia	Average control 3 sites	
bromacil	1.6	2	9	2	91.47	35.35	44.93	57.25	2
diuron	1.6	10	18.5	4	74.45	28.09	22.28	41.61	10
bromacil + diuron	1.6 + 1.6	1	3	1	91.50	45.76	49.39	62.22	1
diuron + oryzalin	1.6 + 1.6	5	15	8	78.62	33.06	15.26	42.31	8
diuron + thiazopyr	1.6 + 0.25	11	13	10	73.57	33.41	13.89	40.29	13
diuron + thiazopyr	1.6 + 0.33	9	16	11	76.14	33.03	12.49	40.55	12
norflurazon	1.6	14	14	14	69.98	33.14	10.95	38.02	15
norflurazon + diuron	1.6 + 1.6	4	1	7	80.76	55.59	17.38	51.24	4
norflurazon + simazine	1.6 + 1.8	12	4	3	73.37	45.54	27.43	48.78	5
norflurazon + oxyfluorfen	1.6 + 0.8	3	2	5	80.85	52.30	21.83	51.66	3
oryzalin	1.6	18	20	19	64.39	23.92	9.2	32.50	19
oxyfluorfen	0.8	15	11	18	69.08	34.02	9.38	37.49	16
oxyfluorfen + thiazopyr	0.8 + 0.25	7	10	13	76.05	34.91	10.98	40.65	11
oxyfluorfen + thiazopyr	0.8 + 0.33	6	5	16	77.66	40.49	10.36	42.50	7
simazine	1.8	20	18.5	20	52.68	28.09	9.08	29.95	20
simazine + oryzalin	1.8 + 1.6	8	8	9	75.05	36.03	14.39	41.82	9
simazine + thiazopyr	1.8 + 0.25	16	6	12	68.87	38.63	11.10	39.53	14
simazine + thiazopyr	1.8 + 0.33	13	7	6	72.45	37.94	18.19	42.86	6
thiazopyr	0.25	19	17	15	61.58	29.76	10.62	33.99	18
thiazopyr	0.33	17	12	17	67.69	33.56	9.62	36.96	17
control	0.0	21	21	21	39.07	14.39	2.29	18.58	21

Table 5-10. Average weed control ranking and average weed control (%) for three sites during the second year where the herbicide use rate was applied at different application rates.

Herbicide	Rate (lb ai/A)		Ranking based upon % weed control at individual site			Average weed control (%)		
	Lake Garfield	Indian-town & Arcadia	Lake Garfield	Indiantown	Arcadia	Lake Garfield	Indiantown	Arcadia
bromacil	1.6	2.13	2	5	6	87.12	81.02	49.97
diuron	1.6	2.13	15	13	17	71.10	59.23	24.38
bromacil + diuron	1.6 + 1.6	2.13 + 2.13	1	2	3	87.38	90.78	72.19
diuron + oryzalin	1.6 + 1.6	2.6 + 2.0	10	10	7	77.42	62.59	41.78
diuron + thiazopyr	1.6 + 0.25	2.13 + 0.38	9	12	13	77.48	60.39	32.43
diuron + thiazopyr	1.6 + 0.33	2.13 + 0.49	8	7	12	77.87	66.30	33.37
norflurazon	1.6	2.4	7	6	5	79.05	80.95	63.37
norflurazon + diuron	1.6 + 1.6	2.13 + 2.4	3	1	4	86.57	92.45	65.48
norflurazon + simazine	1.6 + 1.8	2.4 + 2.64	5	3	1	84.11	89.46	77.18
norflurazon+ oxyfluorfen	1.6 + 0.8	2.4 + 1.2	4	4	2	86.07	88.40	77.03
oryzalin	1.6	2.0	14	20	18	71.83	36.88	24.32
oxyfluorfen	0.8	1.2	12	15	16	73.81	54.77	27.23
oxyfluorfen + thiazopyr	0.8 + 0.25	1.2 + 0.38	11	9	9	76.75	63.75	36.95
oxyfluorfen + thiazopyr	0.8 + 0.33	1.2 + 0.49	6	11	10	81.47	60.72	35.74
simazine	1.8	2.64	20	17	20	45.01	46.63	7.95
simazine + oryzalin	1.8 + 1.6	2.64 + 2.0	17	14	19	70.44	56.55	22.23
simazine + thiazopyr	1.8 + 0.25	2.64 + 0.38	13	8	15	72.21	63.97	31.16
simazine + thiazopyr	1.8 + 0.33	2.64 + 0.49	16	16	8	53.35	53.35	37.01
thiazopyr	0.25	0.375	19	18	14	45.50	45.50	31.41
thiazopyr	0.33	0.49	18	19	11	42.29	42.29	34.26
control	0.0	0.0	21	21	21	28.83	28.83	4.11

caused by ants and footrot (*Phytophthora parasitica*) to numerous trees at that location. This damage resulted in higher than normal tree mortality and poor tree growth of some trees. At Lake Garfield (Table 5-11) and Arcadia (Table 5-12), the canopy volume and trunk cross-sectional diameter measurements did not show any statistical differences among any of the 21 treatments at the end of the experiment or in changes in measurement from the beginning to the end of the experiment in canopy volume or trunk cross-sectional diameter measurements. These findings were not what was expected in light of the published data for citrus (Ryan & Kretchman, 1968; Jordan, 1981; Jordan et al., 1992) or for other tree crops (Foshee et al., 1997; Merwin & Ray, 1997).

A number of factors can be offered as reasons that no differences in tree canopy volume or trunk cross-sectional diameter measurements were observed for the 21 different treatments. Weeds compete with the citrus trees for moisture, nutrients and light. If moisture, nutrients and/or light were not limiting, then tree growth would not be significantly affected. At both locations, water stress was avoided by the use of frequent supplemental irrigation as needed when soil moisture was low. Water could easily be added to the area around the tree as both groves had a low volume microsprinkler irrigation system, which could easily apply water directly to the young tree's root system. Second, nutrients were added directly to the citrus tree's root system via irrigation. Third, light was not a limiting factor as the weeds were eliminated approximately every 120 days with the use of postemergence herbicides. With the use of postemergence herbicides approximately every 120 days, weed competition was almost eliminated in all plots for a period greater that 30 days after herbicide applications, thus

Table 5-11. Preemergence herbicide treatment effects on canopy volume and trunk cross-sectional measurements at Lake Garfield.

Herbicide	Rate First Year (lb ai/A)	Canopy Volume (cubic inches)			Trunk diameter (inches)		
		1995	1997	Change	1995	1997	Change
bromacil	1.6	61,961 a	293,534 a	231,573 a	1.38 a	2.65 a	1.27 a
diuron	1.6	58,591 a	270,010 a	211,420 a	1.33 a	2.64 a	1.31 a
bromacil + diuron	1.6 + 1.6	65,339 a	323,264 a	257,925 a	1.36 a	2.74 a	1.38 a
diuron + oryzalin	1.6 + 1.6	58,185 a	281,932 a	223,747 a	1.37 a	2.67 a	1.31 a
diuron + thiazopyr	1.6 + 0.25	64,991 a	273,178 a	208,774 a	1.38 a	2.60 a	1.21 a
diuron + thiazopyr	1.6 + 0.33	59,574 a	268,716 a	209,142 a	1.38 a	2.55 a	1.18 a
norflurazon	1.6	65,827 a	339,578 a	273,751 a	1.41 a	2.73 a	1.32 a
norflurazon + diuron	1.6 + 1.6	57,272 a	283,853 a	226,581 a	1.33 a	2.69 a	1.32 a
norflurazon + simazine	1.6 + 1.8	59,516 a	300,852 a	241,335 a	1.32 a	2. 69 a	1.37 a
norflurazon + oxyfluorfen	1.6 + 0.8	57,150 a	281,235 a	224,085 a	1.37 a	2.66 a	1.27 a
oryzalin	1.6	57,054 a	293,022 a	235,968 a	1.32 a	2.71 a	1.39 a
oxyfluorfen	0.8	60,323 a	273,312 a	212,989 a	1.35 a	2.63 a	1.28 a
oxyfluorfen + thiazopyr	0.8 + 0.25	54,458 a	253,860 a	199,402 a	1.31 a	2.57 a	1.27 a
oxyfluorfen + thiazopyr	0.8 + 0.33	65,564 a	288,778 a	223,214 a	1.33 a	2.68 a	1.34 a
simazine	1.8	59,518 a	286,240 a	226,722 a	1.35 a	2.60 a	1.24 a
simazine + oryzalin	1.8 + 1.6	65,066 a	299,727 a	234,661 a	1.37 a	2.59 a	1.22 a
simazine + thiazopyr	1.8 + 0.25	62,310 a	263,372 a	201,062 a	1.38 a	2.61 a	1.23 a
simazine + thiazopyr	1.8 + 0.33	54,488 a	246,608 a	192,119 a	1.29 a	2.50 a	1.21 a
thiazopyr	0.25	57,971 a	286,487 a	227,429 a	1.35 a	2.58 a	1.22 a
thiazopyr	0.33	54,311 a	258,329 a	204,018 a	1.33 a	2.58 a	1.24 a
control	0.0	60,595 a	252,293 a	191,698 a	1.32 a	2.49 a	1.17 a

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).

Table 5-12. Preemergence herbicide treatments effects on canopy volume and trunk cross-sectional measurements at Arcadia.

Herbicide	Rate First Year (lb ai/A)	Rate Second Year (lb ai/A)	Canopy Volume (cubic inches)			Trunk diameter (inches)		
			1995	1997	Change	1995	1997	Change
bromacil	1.6	2.13	42,706 a	242,789 a	200,082 a	0.99 a	2.59 a	1.61 a
diuron	1.6	2.13	43,401 a	239,769 a	196,368 a	1.02 a	2.67 a	1.65 a
bromacil + diuron	1.6 + 1.6	2.13 + 2.13	37,643 a	272,126 a	234,483 a	0.95 a	2.64 a	1.68 a
diuron + oryzalin	1.6 + 1.6	2.6 + 2.0	34,790 a	229,119 a	194,330 a	0.93 a	2.57 a	1.64 a
diuron + thiazopyr	1.6 + 0.25	2.13 + 0.38	40,122 a	220,068 a	179,946 a	1.00 a	2.50 a	1.50 a
diuron + thiazopyr	1.6 + 0.33	2.13 + 0.49	39,070 a	233,958 a	194,889 a	0.98 a	2.61 a	1.63 a
norflurazon	1.6	2.4	38,854 a	223,529 a	184,675 a	1.00 a	2.57 a	1.57 a
norflurazon + diuron	1.6 + 1.6	2.13 + 2.4	40,513 a	251,391 a	210,878 a	1.00 a	2.66 a	1.66 a
norflurazon + simazine	1.6 + 1.8	2.4 + 2.64	37,656 a	240,707 a	203,050 a	0.99 a	2.66 a	1.66 a
norflurazon + oxyfluorfen	1.6 + 0.8	2.4 + 1.2	37,398 a	251,948 a	214,551 a	0.96 a	2.61 a	1.65 a
oryzalin	1.6	2.0	36,960 a	250,408 a	213,448 a	0.99 a	2.72 a	1.73 a
oxyfluorfen	0.8	1.2	36,361 a	230,800 a	194,439 a	0.98 a	2.57 a	1.59 a
oxyfluorfen + thiazopyr	0.8 + 0.25	1.2 + 0.38	35,448 a	233,399 a	197,951 a	0.97 a	2.64 a	1.67 a
oxyfluorfen + thiazopyr	0.8 + 0.33	1.2 + 0.49	35,036 a	224,927 a	189,891 a	0.98 a	2.55 a	1.57 a
simazine	1.8	2.64	42,854 a	253,822 a	210,958 a	1.02 a	2.68 a	1.65 a
simazine + oryzalin	1.8 + 1.6	2.64 + 2.0	40,204 a	268,493 a	228,289 a	1.01 a	2.67 a	1.65 a
simazine + thiazopyr	1.8 + 0.25	2.64 + 0.38	41,067 a	232,202 a	191,134 a	0.99 a	2.61 a	1.63 a
simazine + thiazopyr	1.8 + 0.33	2.64 + 0.49	36,664 a	269,068 a	232,404 a	0.97 a	2.62 a	1.65 a
thiazopyr	0.25	0.375	36,715 a	236,239 a	199,524 a	0.97 a	2.65 a	1.67 a
thiazopyr	0.33	0.49	41,121 a	251,563 a	210,442 a	1.02 a	2.74 a	1.72 a
control	0.0	0.0	38,582 a	223,106 a	184,524 a	0.97 a	2.59 a	1.62 a

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).

providing at least 90 days each year that were weed free. Based upon data in Appendix Tables A-1 through A-6 for Lake Garfield, the majority of the herbicide treatments at 60 DAT exceeded 80% weed control, thus reducing any significant weed competition that occurred at that site for almost 50% of the year. For the Arcadia site (Appendix Tables A-13 through A-18), the weed competition was greater than at Lake Garfield at all rating intervals. At 30 DAT the weed control exceeded 90% weed control and was reduced at subsequent ratings. However, weed competition for water, nutrients, or light was not severe enough to reduce tree growth (canopy volume or trunk cross-sesctional area) as measured. This also supports the concept that 100% weed control is not horticulturally necessary. Some weeds present in the under-tree canopy area of the grove, for limited periods of time, will not significantly reduce tree growth as indicated by this study. Weed growth to the extent that occurred in some plots at Arcadia would not have been commercially acceptable due to problems caused by weeds in grove and irrigation maintenance, production operations, and harvesting. Additionally, heavy weed growth during the winter can result in the grove temperatures being 2-4°F (Krezdorn & Martsolf, 1984; Singh & Tucker, 1984) or colder than groves that are weed free, thus increasing the potential for cold damage to the citrus trees.

These findings should not be interpreted to mean that weeds do not compete with citrus trees. If water, nutrients, and/or light had been limiting, the results of this study might have been different.

Based upon the assumption that water and nutrients were not limiting at these sites, the growers most likely were over-applying water and nutrients in those plots that

had successful weed control. By choosing one of the products that did offer acceptable weed control, the growers could possibly reduce water and/or nutrient inputs, and the result could be reduced cost.

Cost of Weed Control

The costs of the preemergence and postemergence herbicide materials are presented in Tables 5-13 through 5-16. These tables were developed using the actual herbicide application rate times three applications per year multiplied by a cost for the materials. Material costs were determined by calling four large agricultural chemical sales companies and obtaining what they considered to be average prices for each of the herbicide products. Average product costs and the cost per pound of active ingredient (lb ai) for the herbicide materials in the study are provided in Table 5-13.

Table 5-13. Herbicide costs.

Common name	Trade name	Product price	Price (lb ai)
bromacil	Hyvar 80WP	$15.81/lb	$19.76
diuron	Direx 80DF	$3.98/lb	$4.98
norflurazon	Solicam 80DF	$13.43/lb	$16.79
oryzalin	Surflan 4AS*	$62.83/lb	$15.71
oxyfluorfen	Goal 1.6E	$85.75/gallon	$53.59
simazine	Princep-Caliber 90	$3.35/lb	$3.72
thiazopyr	Mandate 2E	$164.50/gallon	$82.25
glyphosate	Roundup	$46.37/gallon	$11.59

*Surflan AS price was used since Surflan 80DF is not currently marketed in Florida

Table 5-14. Herbicide cost per percent weed control at Lake Garfield for two years with percent weed control from Table 5-6.

Herbicide	Rate First Year (lb ai/A)	Costs based upon 3 applications per year				Rate Second Year (lb ai/A)	Costs based upon 3 applications per year			
		Pre-emerg. Herb. ($)	Total cost (pre + post) ($)	Ave. annual weed control (%)	Material cost per % weed control ($)		Pre-emerg. Herb. ($)	Total cost (pre + post) ($)	Ave. annual weed control (%)	Material cost per % weed control ($)
bromacil	1.6	94.85	181.78	91	2.00	1.6	94.85	181.78	87	2.09
diuron	1.6	23.90	110.83	74	1.50	1.6	23.90	110.83	71	1.56
bromacil + diuron	1.6 + 1.6	118.75	205.68	92	2.24	1.6 + 1.6	118.75	205.68	87	2.36
diuron + oryzalin	1.6 + 1.6	99.31	186.24	79	2.36	1.6 + 1.6	99.31	186.24	77	2.42
diuron + thiazopyr	1.6+ 0.25	85.59	175.52	74	2.37	1.6 + 0.25	85.59	175.52	77	2.28
diuron + thiazopyr	1.6 + 0.33	106.16	193.09	76	2.54	1.6 + 0.33	106.16	193.09	78	2.48
norflurazon	1.6	80.59	167.52	70	2.39	1.6	80.59	167.52	79	2.12
norflurazon + diuron	1.6 + 1.6	104.49	191.42	81	2.36	1.6 + 1.6	104.49	191.42	87	2.20
norflurazon + simazine	1.6 + 1.8	100.68	187.61	73	2.57	1.6 + 1.8	100.68	187.61	84	2.23
norflurazon + oxyfluorfen	1.6 + 0.8	209.21	296.14	81	3.66	1.6 + 0.8	209.21	296.14	86	3.42
oryzalin	1.6	75.41	162.34	64	2.54	1.6	75.41	162.34	71	2.29
oxyfluorfen	0.8	128.62	215.55	69	3.12	0.8	128.62	215.55	74	2.91
oxyfluorfen + thiazopyr	0.8 + 0.25	190.31	277.24	76	3.65	0.8 + 0.25	190.31	277.24	77	3.60
oxyfluorfen + thiazopyr	0.8 + 0.33	210.87	297.80	78	3.82	0.8 + 0.33	210.87	297.80	81	3.68
simazine	1.8	20.09	107.02	53	2.02	1.8	20.09	107.02	45	2.38
simazine + oryzalin	1.8 + 1.6	95.50	182.43	75	2.43	1.8 + 1.6	95.50	182.43	70	2.61
simazine + thiazopyr	1.8 + 0.25	81.78	168.71	69	2.45	1.8 + 0.25	81.78	168.71	72	2.34
simazine + thiazopyr	1.8 + 0.33	102.34	189.27	72	2.63	1.8 + 0.33	102.34	189.27	71	2.66
thiazopyr	0.25	61.69	148.62	62	2.40	0.25	61.69	148.62	57	2.61
thiazopyr	0.33	82.25	169.18	68	2.49	0.33	82.25	169.18	67	2.53
control	0.0		86.93	39	2.23	0.0		86.93	38	2.29

Table 5-15. Herbicide cost per percent weed control at Indiantown for two years with percent weed control from Table 5-7.

Herbicide	Rate First Year (lb ai/A)	Costs based upon 3 applications per year				Rate Second Year (lb ai/A)	Costs based upon 3 applications per year			
		Pre-emerg. Herb. ($)	Total cost (pre + post) ($)	Ave. annual weed control (%)	Material cost per % weed control ($)		Pre-emerg. Herb. ($)	Total cost (pre + post) ($)	Ave. annual weed control (%)	Material cost per % weed control ($)
bromacil	1.6	94.85	181.78	35	5.19	2.13	126.27	213.20	81	2.63
diuron	1.6	23.90	110.83	28	3.96	2.13	31.82	118.75	59	2.01
bromacil + diuron	1.6 + 1.6	118.75	205.68	46	4.47	2.13 + 2.13	158.09	245.02	91	2.69
diuron + oryzalin	1.6 + 1.6	99.31	186.24	33	5.64	2.6 + 2.0	126.08	213.01	63	3.38
diuron + thiazopyr	1.6 + 0.25	85.59	172.52	33	5.23	2.13 + 0.38	124.35	211.28	60	3.52
diuron + thiazopyr	1.6 + 0.33	106.16	193.09	33	5.85	2.13 + 0.49	152.73	239.66	66	3.63
norflurazon	1.6	80.59	167.52	33	5.08	2.4	120.89	207.82	81	2.57
norflurazon + diuron	1.6 + 1.6	104.49	191.42	56	3.42	2.4 + 2.13	152.71	271.46	92	2.95
norflurazon + simazine	1.6 + 1.8	100.68	187.61	46	4.08	2.4 + 2.64	150.35	237.28	89	2.66
norflurazon + oxyfluorfen	1.6 + 0.8	209.21	296.14	52	5.70	2.4 + 1.2	313.81	400.74	88	4.55
oryzalin	1.6	75.41	162.34	24	6.76	2.0	94.26	181.19	37	4.90
oxyfluorfen	0.8	128.62	215.55	34	6.34	1.2	192.92	279.85	55	5.09
oxyfluorfen + thiazopyr	0.8 + 0.25	190.31	277.24	35	7.91	1.2 + 0.38	285.45	372.38	64	5.82
oxyfluorfen + thiazopyr	0.8 + 0.33	210.87	297.80	40	7.45	1.2 + 0.49	313.83	400.76	61	6.57
simazine	1.8	20.09	107.02	28	3.82	2.64	29.46	116.39	47	2.48
simazine + oryzalin	1.8 + 1.6	95.50	182.43	36	5.07	2.64 + 2.0	123.72	210.65	57	3.70
simazine + thiazopyr	1.8 + 0.25	81.78	168.71	39	4.33	2.64 + 0.38	121.99	208.92	64	3.26
simazine + thiazopyr	1.8 + 0.33	102.34	189.27	38	4.98	2.64 + 0.49	150.37	237.30	53	4.48
thiazopyr	0.25	61.69	148.62	30	4.95	0.375	92.53	179.46	46	3.90
thiazopyr	0.33	82.25	169.18	34	4.98	0.49	120.91	207.84	42	4.95
control	0.0		86.93	14	6.21	0.0		86.93	29	3.00

Table 5-16. Herbicide cost per percent weed control at Arcadia for two years with percent weed control from Table 5-8.

Herbicide	Rate First Year (lb ai/A)	Costs based upon 3 applications per year				Rate Second Year (lb ai/A)	Costs based upon 3 applications per year			
		Pre-emerg. Herb. ($)	Total cost (pre + post) ($)	Ave. annual weed control (%)	Material cost per % weed control ($)		Pre-emerg. Herb. ($)	Total cost (pre + post) ($)	Ave. Annual weed control (%)	Material cost per % weed control ($)
bromacil	1.6	94.83	181.78	44	4.13	2.13	126.27	213.20	50	4.26
diuron	1.6	23.91	110.83	22	5.04	2.13	31.82	118.75	24	4.95
bromacil + diuron	1.6 + 1.6	118.74	205.68	49	4.20	2.13 + 2.13	158.09	245.02	72	3.40
diuron + oryzalin	1.6 + 1.6	99.31	186.24	15	12.42	2.6 + 2.0	126.08	213.01	42	5.07
diuron + thiazopyr	1.6 + 0.25	85.59	172.52	14	12.32	2.13 + 0.38	124.35	211.28	32	6.60
diuron + thiazopyr	1.6 + 0.33	106.16	193.09	12	16.09	2.13 + 0.49	152.73	239.66	33	7.26
norflurazon	1.6	80.59	167.52	11	15.23	2.4	120.89	207.82	63	3.30
norflurazon + diuron	1.6 + 1.6	104.49	191.42	17	11.26	2.13 + 2.4	152.71	239.64	65	3.69
norflurazon + simazine	1.6 + 1.8	100.68	187.61	27	6.95	2.4 + 2.64	150.35	237.28	77	3.08
norflurazon + oxyfluorfen	1.6 + 0.8	209.21	296.14	22	13.46	2.4 + 1.2	313.81	400.74	77	5.20
oryzalin	1.6	75.41	162.34	9	18.04	2.0	94.26	181.19	24	7.55
oxyfluorfen	0.8	128.62	215.55	9	23.95	1.2	192.92	279.85	27	10.37
oxyfluorfen + thiazopyr	0.8 + 0.25	190.31	277.24	11	25.20	1.2 + 0.38	285.45	372.38	37	10.06
oxyfluorfen + thiazopyr	0.8 + 0.33	210.87	297.80	10	29.78	1.2 + 0.49	313.83	400.76	36	11.13
simazine	1.8	20.09	107.02	9	11.89	2.64	29.46	116.39	8	14.55
simazine + oryzalin	1.8 + 1.6	95.50	182.43	14	13.03	2.64 + 2.0	123.72	210.65	22	9.58
simazine + thiazopyr	1.8 + 0.25	81.78	168.71	11	15.34	2.64 + 0.38	121.99	208.92	31	6.74
simazine + thiazopyr	1.8 + 0.33	102.34	189.27	18	10.52	2.64 + 0.49	150.37	237.30	37	6.41
thiazopyr	0.25	61.69	148.62	11	13.51	0.375	92.53	179.46	31	5.79
thiazopyr	0.33	82.25	169.18	10	16.92	0.49	120.91	207.84	34	6.11
control	0.0		86.93	2	43.47	0.0		86.93	4	21.73

In the studies, three applications were made each year with an average of 2.5 lb ai glyphosate being applied as a postemergence herbicide to kill any existing weeds in the plots.

Comparisons within a specific site (Table 5-14, 5-15, 5-16) can be made for products with similar weed control ratings to determine which herbicide or herbicide combination provided the most economical weed control. Take for example bromacil + diuron, norflurazon + diuron and norflurazon + oxyfluorfen at Lake Garfield. During the second year these herbicide combinations provided an average annual weed control rating of 87%, 87%, and 86%, respectively, and percent weed control cost was \$2.36, \$2.20, and \$3.42. Thus, in this case, the least expensive cost per percent weed control would be the norflurazon + diuron, followed by bromacil + diuron (7.3% increase) over the norflurazon + diuron, and the most expensive mix would be norflurazon + oxyfluorfen (55.5% increase).

Based upon findings presented earlier in this chapter regarding tree growth, 100% weed control on an annual basis was not necessary. In developing the most economical weed control program, additional cost incurred due to poor weed control should be considered. These additional costs could result in increased maintenance costs for irrigation systems, increased time to preform production operations due to weeds or the effect weeds may have on environmental conditions like reducing winter temperatures.

To determine the total herbicide cost per grove acre, multiply the total material cost by the percentage of the grove acre to be treated with herbicides and add the cost for application, which currently is approximately \$11.50 per grove acre.

Conclusions

All preemergence herbicide treatments provided significantly greater weed control than did the control which received only a postemergence herbicide, however, rates per treated acre should be adjusted with site and conditions. Factors affecting weed control include weed species present, weed vigor, season of the year, and environmental conditions. Weed control was the highest in the winter application time period for all products. Highest weed control ratings were on the Ridge (Lake Garfield) and lowest in the Flatwoods (Arcadia), even when herbicide rates were increased in the Flatwoods during the second year as compared to the Ridge.

It is especially important to achieve successful weed control before embarking on a program that uses lower rates per treated acre. Once successful weed control is not achieved, it is very difficult regain control in the short run, as was the case in Arcadia.

Treatment combinations which included norflurazon or bromacil provided the highest level of weed control. Even when treatment combinations included norflurazon and bromacil, the rates should be adjusted to control the weeds present at a given site. Norflurazon weed control ratings improved with time.

Weeds compete with the citrus tree for moisture, nutrients, and/or light. If any factor(s) become limiting, then tree growth will be reduced. In this study, reducing weed populations three times per year with the use of postemergence herbicides provided sufficient control of weeds to limit differences in tree growth from occurring between the 21 treatments as determined by canopy volume or trunk cross-sectional measurements.

Since differences in tree growth were not obtained, results would indicate that moisture, nutrients, and/or light were not limiting under the conditions of this study. Moisture and/or nutrients had to be in excessive quantities for the treatments with acceptable weed control to allow sufficient quantities to be available to meet the needs of both tree and weed growth in treatments that have poor weed control; therefore, possible cost savings could have been achieved by reducing inputs in some treatments.

The cost per percent weed control varied between the three sites for any given treatment. Comparisons between treatments which provided similar weed control ratings can be made comparing cost per percent weed control. As in the earlier example at Lake Garfield during the second year, the price for similar weed control ranged from \$2.20 to \$3.42 per percent weed control or a difference of 55%.

Weed control studies should examine not only the effectiveness of herbicide for weed control but also take into consideration herbicide rate, site location, environmental impact, effect on the tree, and economic cost of the herbicide products in formulating and recommending a herbicide program.

CHAPTER 6
CONCLUSIONS

Herbicide Effect on Growth of Seedlings

Herbicides can reduce shoot and root growth of citrus seedlings if they are applied above current recommended rates for young trees. Bromacil, at high rates, reduced root and shoot growth at a higher frequency than did diuron or other herbicide products. Growers should be aware of the potential for damage to trees and avoid higher application rates on young trees in either new plantings or where resets exist in mature groves. If only mild phytoxicity symptoms appear on seedlings or young trees, the trees should not suffer long-term tree damage if no additional applications at damaging rates are applied. In cases where phytoxicity symptoms were noted, as subsequent flushes emerged, they were free of symptoms, indicating that the damage to the seedling was temporary in nature and in most cases the seedling would not suffer long-term damage.

Differential Rootstock Susceptibility

All rootstocks do not respond in the same manner to herbicide applications. Swingle (46%) and Carrizo (26%) represented approximately 72% of the nursery propagations in 1996-97 (Division of Plant Industry, 1997). Carrizo has been shown to

have greater sensitivity to herbicides than has Swingle, as noted by visual differences and weight measurements in roots and shoots.

Off-Target Species Susceptibility

Off target species (live oaks), which are located in adjacent property and have roots extending into the citrus grove, can be damaged with herbicide applications that are completely safe to citrus trees. Applications of bromacil, norflurazon and diuron at rates as low as 1.6 lb ai/A have been shown to damage live oak seedlings. Due to potential problems that might occur, caution should be used when applying these herbicides in areas where oak roots may be present.

Leaching Potential

Herbicides used in Florida citrus have different leaching potential, allowing movement into Florida's shallow groundwater supplies or moving laterally into surface water. Individuals should be aware of these potential contamination problems and select those herbicides that will minimize potential water contamination problems. Of the herbicides in this study, bromacil was clearly shown to have the greatest potential to move through the soils when using soil columns and Chemical Movement in Layered Soils (CMLS) computer programs.

By selecting herbicides that have lower leaching potential, growers can decrease the chances of adversely affecting ground and surface water quality. Combinations of certain herbicides, soils types and production practices can pose a real and significant risk

to water quality. Growers should select herbicides that reduce environmental risks. If an herbicide product is chosen that has a high leaching potential, it should be especially avoided during the year when heavy rainfall periods are likely, thus minimizing potential movement of the herbicide into the groundwater sources. As rainfall rates were increased, herbicides which were highly mobile in soils moved to a greater depth with increasing rates. Irrigation applications should be scheduled in a manner that does not adversely affect herbicide movement. Water should be replaced only to the extent that it has been removed from the soil and not applied for long durations, which tends to leach the herbicides from the zone of weed seed germination.

Estimating Herbicide Mobility

While computer models are an effective tool in estimating herbicide movement in the soil, a complete understanding of the model inputs should be clearly understood. To effectively predict herbicide movement, full knowledge of the organic carbon adsorption coefficient (K_{oc}) values for the specific soil type should be used. Using average K_{oc} may cause either under- or overprediction of the herbicide movement for the studied soil. However, if quick comparisons between herbicides are desired, the average K_{oc} values will allow for a ranking between those products, but they should be used with caution to make statements about how an herbicide would act in specific field conditions.

Weed Control in Field Studies

From this study it has been shown that weeds can be effectively controlled, but products and rates must be adjusted depending on weed vigor, weed species present and environmental conditions. Herbicide combinations that included bromacil or norflurazon generally provided higher levels of weed control. Weed intensities varied among the different locations within the state with the highest weed pressure being located at the Arcadia (South Central) and the lowest at Lake Garfield (Central Ridge). Herbicide rates must be adjusted to control the weeds present at the specific site. Herbicide products and/or rates that work at one location may not provide effective control at other locations. A clear understanding of weed species present and knowledge of species that are controlled by a given herbicide are important.

Weed control of approximately 80% at the end of the rating period should provide acceptable control under most conditions. Complete weed control (100%) is not necessary, may not be cost effective and could pose environmental risks. Seasonal differences in weed control will occur, with lower levels of weed pressure occurring during the winter months. This lower weed pressure could allow for reduced application rates during this time period, thus reducing herbicide costs.

Tree Growth

Weeds compete with the tree for nutrients, water and space. The competitive nature of weeds has reduced tree growth in several studies. Differences between

acceptable (greater than 80%) and unacceptable (less than 80%) weed control did not correspond to reduced tree growth at two of the reported sites. This should not imply that excessive weed growth does not affect tree growth. Weeds will affect a number of other horticultural and environmental factors as well as the ability to work around the citrus tree, maintain irrigation systems, apply various chemicals and harvesting costs. All treatments did have all weeds removed three times per year, which provided at least one-quarter of the year in a weed-free condition. Since data on fertilizer and water use were not obtained, the possibility does exist that the sites were not limited for inputs and true competition did not exist between the tree and weeds for nutrients and water. If inputs were limited, differences in tree growth between weed control ratings should have occurred. If inputs were not limited, some plots, especially those that had good weed control, were most likely receiving excessive inputs, whereas those with poor weed control were receiving sufficient inputs to meet the needs of the tree and weeds.

Other Considerations

Florida citrus growers should combine horticultural and ecological considerations in an effort to produce citrus in an environmentally friendly and economically viable manner while effectively controlling weeds and production costs. With Florida's warm climate, often abundant rainfall, sandy soil and variable site conditions, the task of weed control is a complex operation that should not be taken lightly. Weed control practices of previous years may have been effective in controlling weeds but may not be economically or ecologically prudent in today's business environment. A choice of herbicide rates that

are effective in suppressing or controlling weed growth in one location may not offer sufficient control in another location; thus, citrus growers must develop site-specific recommendations for each location within the state. Site-specific recommendations can include, but are not limited to, the use of one or more preemergence herbicides, the use of different preemergence herbicide application rates, or the use of pre- and postemergence herbicides in combination to control germination of weed seeds as well as weeds that have already germinated.

In establishing an effective weed control program, the site should be surveyed to determine the weeds present and develop an herbicide program that will provide effective and economical weed control. The herbicide program may use a combination of pre- and postemergence herbicide materials to control emerged as well as emerging weed species. Herbicide rate(s) should be high enough to control the weeds species present. Once successful weed control is obtained with a given herbicide combination, the herbicide program may allow for an adjustment in herbicide rate. It is essential first to obtain effective control at a given site before utilizing lower rates. Once effective weed control is lost, it is more difficult to obtain acceptable weed control with future applications of either pre- or postemergence herbicides.

Herbicide application frequency can have an impact on tree safety as well as leaching potential. On a yearly basis, three applications would result in lower per application rates per acre of herbicide resulting in a smaller phytoxicity risks to young trees as well as reducing potential leaching than only two applications per year at higher rates.

APPENDIX
AVERAGE WEED CONTROL RATINGS

Table A-1. Lake Garfield first weed control ratings, application date May 15, 1995 .

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT
1	bromacil	1.6	99.1 ab	96.8 a	93.2 a	92.4 a
2	diuron	1.6	97.8 abc	90.2 abc	84.4 ab	80.5 abc
3	bromacil + diuron	1.6 + 1.6	99.6 a	95.0 ab	93.2 a	90.5 ab
4	diuron + oryzalin	1.6 + 1.6	96.3 b-e	86.7 bcd	78.8 a-d	74.0 b-e
5	diuron + thiazopyr	1.6 + .25	92.8 d-g	80.8 c-f	67.5 b-f	66.5 c-f
6	diuron + thiazopyr	1.6 + 0.325	94.9 c-f	81.5 c-f	71.8 b-e	68.0 c-f
7	norflurazon	1.6	88.4 g	77.3 c-g	60.7 c-f	56.8 d-g
8	diuron + norflurazon	1.6 + 1.6	94.2 c-g	81.4 c-f	74.7 b-e	73.3 b-e
9	norflurazon + simazine	1.6 + 1.8	89.0 fg	72.9 d-g	68.2 b-f	60.3 c-g
10	norflurazon + oxyfluorfen	1.6 + 0.8	96.3 b-e	87.1 a-d	80.3 abc	77.9 a-d
11	oryzalin	1.6	88.0 g	71.3 efg	57.3 ef	47.6 fg
12	oxyfluorfen	0.8	94.3 c-g	80.6 c-f	69.6 b-f	65.1 c-f
13	oxyfluorfen + thiazopyr	0.8 + 0.25	96.7 bcd	86.1 b-e	84.5 ab	80.9 abc
14	oxyfluorfen + thiazopyr	0.8 + 0.325	96.7 bcd	86.3 b-e	81.7 ab	81.7 abc
15	simazine	1.8	91.1 efg	63.1 g	48.51 fg	38.1 gh
16	simazine + oryzalin	1.8 + 1.6	95.7 b-e	82.3 c-f	67.3 b-f	61.2 c-g
17	simazine + thiazopyr	1.8 + 0.25	94.0 c-g	78.7 c-g	73.7 b-e	66.4 c-f
18	simazine + thiazopyr	1.8 + 0.325	93.9 c-g	84.1 b-f	73.1 b-e	65.7 c-f
19	thiazopyr	0.25	88.0 g	69.4 fg	59.7 def	54.1 efg
20	thiazopyr	0.325	94.5 c-g	80.6 c-f	72.3 b-e	69.4 c-f
21	control	0.0	71.9 h	37.9 h	29.4 g	23.3 h

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.

Table A-2. Lake Garfield second weed control ratings, application date September 6, 1995.

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT
1	bromacil	1.6	99.0 a	99.0 a	95.0 a	88.4 a-d
2	diuron	1.6	99.0 a	99.0 a	93.2 abc	86.2 bcd
3	bromacil + diuron	1.6 + 1.6	99.0 a	99.0 a	95.0 a	90.2 ab
4	diuron + oryzalin	1.6 + 1.6	99.0 a	98.4 ab	94.1 ab	88.2 a-d
5	diuron + thiazopyr	1.6 + .25	99.0 a	99.0 a	95.0 a	87.1 a-d
6	diuron + thiazopyr	1.6 + 0.325	99.0 a	99.0 a	94.1 ab	86.5 a-d
7	norflurazon	1.6	99.0 a	98.4 ab	95.0 a	87.4 a-d
8	diuron + norflurazon	1.6 + 1.6	99.0 a	99.0 a	95.0 a	89.3 abc
9	norflurazon + simazine	1.6 + 1.8	99.0 a	99.0 a	93.4 abc	90.0 ab
10	norflurazon + oxyfluorfen	1.6 + 0.8	99.0 a	99.0 a	95.0 a	92.2 a
11	oryzalin	1.6	99.0 a	98.4 ab	94.1 ab	85.6 bcd
12	oxyfluorfen	0.8	99.0 a	99.0 a	94.1 ab	91.4 ab
13	oxyfluorfen + thiazopyr	0.8 + 0.25	99.0 a	99.0 a	94.1 ab	91.1 ab
14	oxyfluorfen + thiazopyr	0.8 + 0.325	99.0 a	99.0 a	95.0 a	91.1 ab
15	simazine	1.8	99.0 a	95.3 c	92.2 abc	82.9 cd
16	simazine + oryzalin	1.8 + 1.6	99.0 a	98.4 ab	95.0 a	88.8 a-d
17	simazine + thiazopyr	1.8 + 0.25	99.0 a	99.0 a	95.0 a	86.2 bcd
18	simazine + thiazopyr	1.8 + 0.325	99.0 a	98.4 ab	94.1 ab	87.4 a-d
19	thiazopyr	0.25	99.0 a	95.3 c	90.8 c	82.5 d
20	thiazopyr	0.325	99.0 a	97.8 b	91.7 bc	86.2 bcd
21	control	0.0	96.0 b	82.8 d	79.0 d	73.5 e

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.

Table A-3. Lake Garfield third weed control ratings, application date February 9, 1996.

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT
1	bromacil	1.6	98.4 ab	93.2 ab	92.4 ab	94.1 a
2	diuron	1.6	98.4 ab	86.2 cde	81.9 c-f	56.5 efg
3	bromacil + diuron	1.6 + 1.6	99.0 a	95.0 a	95.0 a	94.1 a
4	diuron + oryzalin	1.6 + 1.6	98.4 ab	88.1 cd	85.3 bcd	73.8 bc
5	diuron + thiazopyr	1.6 + .25	97.8 ab	84.3 c-f	82.3 cde	66.6 b-f
6	diuron + thiazopyr	1.6 + 0.325	99.0 a	88.5 bc	84.9 bcd	74.1 bc
7	norflurazon	1.6	97.0 abc	80.2 e-h	76.3 d-g	65.5 c-f
8	diuron + norflurazon	1.6 + 1.6	98.4 ab	88.5 bc	87.6 bc	80.6 b
9	norflurazon + simazine	1.6 + 1.8	97.8 ab	85.3 c-f	82.3 cde	69.7 b-e
10	norflurazon + oxyfluorfen	1.6 + 0.8	99.0 a	85.1 c-f	80.1 c-f	73.2 bcd
11	oryzalin	1.6	98.0 ab	83.5 c-f	80.5 c-f	58.9 c-g
12	oxyfluorfen	0.8	96.0 bcd	79.0 fgh	72.1 fg	50.9 fg
13	oxyfluorfen + thiazopyr	0.8 + 0.25	98.4 ab	82.3 def	79.1 c-f	57.1 d-g
14	oxyfluorfen + thiazopyr	0.8 + 0.325	97.0 abc	81.1 efg	79.2 c-f	61.2 c-g
15	simazine	1.8	85.8 f	68.9 i	56.7 hi	33.3 h
16	simazine + oryzalin	1.8 + 1.6	98.4 ab	87.5 cd	82.4 cde	72.9 bcd
17	simazine + thiazopyr	1.8 + 0.25	93.0 cde	80.6 e-h	72.4 efg	54.1 efg
18	simazine + thiazopyr	1.8 + 0.325	96.6 abc	83.8 c-f	76.9 d-g	63.0 c-g
19	thiazopyr	0.25	90.6 ef	74.4 ghi	66.5 gh	47.9 gh
20	thiazopyr	0.325	92.2 de	73.4 hi	67.7 gh	48.0 gh
21	control	0.0	75.1 g	58.3 j	46.6 i	16.7 i

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.

Table A-4. Lake Garfield fourth weed control ratings, application date June 20, 1996.

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT
1	bromacil	1.6	99.0 a	97.8 a	86.8 ab	80.2 ab
2	diuron	1.6	96.3 b-e	78.4 def	72.0 b-e	63.7 c-f
3	bromacil + diuron	1.6 + 1.6	99.0 a	96.9 ab	88.2 a	81.4 a
4	diuron + oryzalin	1.6 + 1.6	98.4 ab	88.8 b-e	73.5 b-e	67.5 a-f
5	diuron + thiazopyr	1.6 + .25	97.0 a-d	83.8 def	70.1 c-f	64.3 b-f
6	diuron + thiazopyr	1.6 + 0.325	97.8 abc	87.2 c-f	72.8 b-e	67.5 a-f
7	norflurazon	1.6	94.1 def	82.6 def	70.1 c-f	69.3 a-f
8	diuron + norflurazon	1.6 + 1.6	98.4 ab	94.8 abc	84.1 abc	79.3 abc
9	norflurazon + simazine	1.6 + 1.8	97.0 a-d	90.3 a-d	74.4 a-e	74.5 a-e
10	norflurazon + oxyfluorfen	1.6 + 0.8	98.4 ab	91.1 a-d	79.3 a-d	78.1 a-d
11	oryzalin	1.6	97.8 abc	84.1 c-f	62.6 d-g	62.4 def
12	oxyfluorfen	0.8	95.3 cde	74.4 f	69.2 c-f	63.1 c-f
13	oxyfluorfen + thiazopyr	0.8 + 0.25	97.0 a-d	81.1 def	67.2 def	70.2 a-f
14	oxyfluorfen + thiazopyr	0.8 + 0.325	97.0 a-d	79.5 def	71.1 c-f	73.1 a-e
15	simazine	1.8	90.8 fg	48.5 g	33.3 hi	29.9 hi
16	simazine + oryzalin	1.8 + 1.6	96.0 b-e	87.3 c-f	69.5 c-f	59.8 ef
17	simazine + thiazopyr	1.8 + 0.25	93.4 ef	75.6 ef	64.1 d-g	61.2 ef
18	simazine + thiazopyr	1.8 + 0.325	95.7 cde	73.6 f	56.5 efg	55.4 fg
19	thiazopyr	0.25	88.5 g	54.9 g	45.9 gh	41.8 gh
20	thiazopyr	0.325	93.2 ef	73.3 f	53.2 fg	58.6 efg
21	control	0.0	81.5 h	38.7 g	21.2 i	21.7 i

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.

Table A-5. Lake Garfield fifth weed control ratings, application date December 23, 1996.

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT
1	bromacil	1.6	99.0 a	99.0 a	98.4 a	94.1 a
2	diuron	1.6	99.0 a	97.0 abc	93.7 c-f	84.9 cde
3	bromacil + diuron	1.6 + 1.6	99.0 a	97.8 abc	97.8 ab	94.7 a
4	diuron + oryzalin	1.6 + 1.6	99.0 a	96.0 bcd	95.0 b-e	89.7 a-d
5	diuron + thiazopyr	1.6 + .25	99.0 a	96.0 bcd	96.0 a-d	87.2 b-e
6	diuron + thiazopyr	1.6 + 0.325	99.0 a	97.0 abc	97.0 abc	88.5 a-e
7	norflurazon	1.6	99.0 a	97.0 abc	95.3 b-e	85.9 b-e
8	diuron + norflurazon	1.6 + 1.6	99.0 a	98.4ab	97.8 ab	92.4 ab
9	norflurazon + simazine	1.6 + 1.8	99.0 a	97.0 abc	96.0 a-d	91.4 abc
10	norflurazon + oxyfluorfen	1.6 + 0.8	99.0 a	98.4 ab	96.0 a-d	91.1 abc
11	oryzalin	1.6	99.0 a	97.0 abc	94.0 c-f	86.6 b-e
12	oxyfluorfen	0.8	99.0 a	95.3 cde	90.2 fgh	80.3 efg
13	oxyfluorfen + thiazopyr	0.8 + 0.25	99.0 a	95.3 cde	92.2 d-g	87.1 b-e
14	oxyfluorfen + thiazopyr	0.8 + 0.325	99.0 a	97.0 abc	94.1 c-f	89.1 a-d
15	simazine	1.8	99.0 a	91.1 f	85.8 h	72.9 gh
16	simazine + oryzalin	1.8 + 1.6	99.0 a	97.0 abc	97.0 abc	88.5 a-e
17	simazine + thiazopyr	1.8 + 0.25	99.0 a	97.0 abc	91.4 e-h	83.2 def
18	simazine + thiazopyr	1.8 + 0.325	99.0 a	96.0 bcd	94.4 b-f	87.0 b-e
19	thiazopyr	0.25	99.0 a	93.2 def	88.5 gh	75.3 fgh
20	thiazopyr	0.325	99.0 a	96.0 bcd	91.4 e-h	83.2 def
21	control	0.0	99.0 a	92.2 ef	86.4 h	67.4 h

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.

Table A-6. Lake Garfield sixth weed control ratings, application date April 25, 1997.

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT
1	bromacil	1.6	99.0 a	97.8 ab	93.4 abc	87.2 abc
2	diuron	1.6	99.0 a	94.7 b-f	80.7 ef	64.2 f-i
3	bromacil + diuron	1.6 + 1.6	99.0 a	97.8 ab	94.7 a	86.2 a-d
4	diuron + oryzalin	1.6 + 1.6	99.0 a	96.0 a-e	89.3 a-e	75.2 a-h
5	diuron + thiazopyr	1.6 + .25	99.0 a	96.0 a-e	87.3 a-e	80.8 a-f
6	diuron + thiazopyr	1.6 + 0.325	99.0 a	97.0 a-d	88.3 a-e	77.7 a-h
7	norflurazon	1.6	99.0 a	94.1 c-f	87.6 a-e	82.3 a-e
8	diuron + norflurazon	1.6 + 1.6	99.0 a	97.2 abc	90.5 a-d	88.1 ab
9	norflurazon + simazine	1.6 + 1.8	99.0 a	95.3 b-f	93.2 abc	86.7 abc
10	norflurazon + oxyfluorfen	1.6 + 0.8	99.0 a	98.4 a	94.1 ab	89.3 a
11	oryzalin	1.6	99.0 a	94.6 b-f	85.3 c-f	66.1 e-i
12	oxyfluorfen	0.8	99.0 a	91.4 fgh	83.3 def	79.1 a-g
13	oxyfluorfen + thiazopyr	0.8 + 0.25	99.0 a	94.1 c-f	86.2 b-f	73.1 b-h
14	oxyfluorfen + thiazopyr	0.8 + 0.325	99.0 a	95.0 b-f	90.0 a-e	82.3 a-e
15	simazine	1.8	99.0 a	86.5 h	64.1 g	30.0 j
16	simazine + oryzalin	1.8 + 1.6	99.0 a	96.0 a-e	86.2 b-f	62.1 ghi
17	simazine + thiazopyr	1.8 + 0.25	99.0 a	93.2 efg	86.2 b-f	72.2 c-h
18	simazine + thiazopyr	1.8 + 0.325	99.0 a	93.5 def	85.0 c-f	70.1 d-i
19	thiazopyr	0.25	99.0 a	88.4 gh	75.9 fg	52.1 i
20	thiazopyr	0.325	99.0 a	93.2 efg	85.1 c-f	59.8 hi
21	control	0.0	96.3 b	76.3 i	45.5 h	18.2 j

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.

Table A-7. Indiantown first weed control ratings, application date June 8, 1995.

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT*
1	bromacil	1.6	99.0 a	71.2 cd	20.4 cde	
2	diuron	1.6	99.0 a	65.2 d	16.5 cde	
3	bromacil + diuron	1.6 + 1.6	99.0 a	78.2 abc	21.9 bcd	
4	diuron + oryzalin	1.6 + 1.6	99.0 a	71.9 bcd	18.6 cde	
5	diuron + thiazopyr	1.6 + .25	99.0 a	66.3 d	18.5 cde	
6	diuron + thiazopyr	1.6 + 0.325	99.0 a	71.1 cd	19.5 cde	
7	norflurazon	1.6	99.0 a	75.5 abc	23.7 a-d	
8	diuron + norflurazon	1.6 + 1.6	99.0 a	80.1 a	32.8 ab	
9	norflurazon + simazine	1.6 + 1.8	99.0 a	75.1 abc	26.7 abc	
10	norflurazon + oxyfluorfen	1.6 + 0.8	99.0 a	81.1 a	34.9 a	
11	oryzalin	1.6	99.0 a	66.4 d	15.7 de	
12	oxyfluorfen	0.8	99.0 a	72.1 bcd	17.6 cde	
13	oxyfluorfen + thiazopyr	0.8 + 0.25	99.0 a	76.1 abc	21.6 cd	
14	oxyfluorfen + thiazopyr	0.8 + 0.325	99.0 a	76.5 abc	24.4 a-d	
15	simazine	1.8	99.0 a	65.2 de	15.6 de	
16	simazine + oryzalin	1.8 + 1.6	99.0 a	80.2 a	17.2 cde	
17	simazine + thiazopyr	1.8 + 0.25	99.0 a	79.1 ab	19.5 cde	
18	simazine + thiazopyr	1.8 + 0.325	99.0 a	76.1 abc	24.9 a-d	
19	thiazopyr	0.25	99.0 a	72.1 bcd	20.7 cde	
20	thiazopyr	0.325	99.0 a	71.1 cd	22.2 bcd	
21	control	0.0	99.0 a	56.2 e	11.9 e	

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.
* Did not rate at 120 days due to poor weed control at 90 days.

Table A- 8. Indiantown second weed control ratings, application date November 17, 1995.

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT
1	bromacil	1.6	99.0 a	99.0 a	95.0 bcd	84.4 b-f
2	diuron	1.6	99.0 a	96.1 b-e	93.4 cde	74.2 e-i
3	bromacil + diuron	1.6 + 1.6	99.0 a	99.0 a	99.0 a	95.3 a
4	diuron + oryzalin	1.6 + 1.6	99.0 a	97.5 a-d	93.7 b-e	76.3 d-i
5	diuron + thiazopyr	1.6 + .25	99.0 a	97.7 a-d	93.2 cde	79.1 c-h
6	diuron + thiazopyr	1.6 + 0.325	99.0 a	97.0 a-d	92.0de	78.5 c-h
7	norflurazon	1.6	99.0 a	94.3 de	89.0 ef	71.4 f-i
8	diuron + norflurazon	1.6 + 1.6	99.0 a	98.4 ab	97.0 abc	91.7 ab
9	norflurazon + simazine	1.6 + 1.8	99.0 a	99.0 a	97.8 ab	89.7 abc
10	norflurazon + oxyfluorfen	1.6 + 0.8	99.0 a	99.0 a	96.0 a-d	87.2 a-d
11	oryzalin	1.6	99.0 a	85.0 f	76.8 gh	48.8 j
12	oxyfluorfen	0.8	99.0 a	98.4 ab	95.0 bcd	82.2 b-g
13	oxyfluorfen + thiazopyr	0.8 + 0.25	99.0 a	96.3 a-d	91.7 de	71.4 f-i
14	oxyfluorfen + thiazopyr	0.8 + 0.325	99.0 a	97.5 a-d	92.0de	78.6 c-h
15	simazine	1.8	99.0 a	96.6 a-d	91.0 de	67.6 hi
16	simazine + oryzalin	1.8 + 1.6	99.0 a	98.4 ab	95.3 bcd	86.6 a-e
17	simazine + thiazopyr	1.8 + 0.25	99.0 a	99.0 a	95.3 bcd	85.7 b-e
18	simazine + thiazopyr	1.8 + 0.325	99.0 a	97.9 abc	93.4 cde	79.5 c-h
19	thiazopyr	0.25	99.0 a	91.6 e	83.6 fg	62.5 ij
20	thiazopyr	0.325	99.0 a	95.1 cde	88.5 ef	71.1 ghi
21	control	0.0	98.3 b	77.2 g	71.1 h	32.0 k

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.

Table A- 9. Indiantown third weed control ratings, application date March 22, 1996.

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT
1	bromacil	1.6	97.8 a	79.5 b-f	54.2 e-h	7.6 e-h
2	diuron	1.6	99.0 a	62.1 gh	22.1 kl	2.3 ghi
3	bromacil + diuron	1.6 + 1.6	99.0 a	92.4 a	80.1 ab	18.5 cd
4	diuron + oryzalin	1.6 + 1.6	98.4 a	71.5 d-h	41.5 ghi	5.5 e-i
5	diuron + thiazopyr	1.6 + .25	98.4 a	74.7 c-g	42.9 ghi	5.5 e-i
6	diuron + thiazopyr	1.6 + 0.325	98.4 a	72.9 c-g	50.0 f-i	6.7 e-h
7	norflurazon	1.6	99.0 a	81.3 b-e	70.9 a-e	13.4 cde
8	diuron + norflurazon	1.6 + 1.6	99.0 a	89.7 ab	83.9 a	39.9 a
9	norflurazon + simazine	1.6 + 1.8	98.4 a	88.1 ab	74.5 a-d	21.2 bc
10	norflurazon + oxyfluorfen	1.6 + 0.8	99.0 a	88.8 ab	78.3 abc	33.6 ab
11	oryzalin	1.6	98.4 a	58.2 h	11.2 lm	4.5 e-i
12	oxyfluorfen	0.8	98.4 a	76.3 c-f	38.7 h-k	3.3 e-i
13	oxyfluorfen + thiazopyr	0.8 + 0.25	99.0 a	83.8 abc	63.5 b-f	10.6 c-f
14	oxyfluorfen + thiazopyr	0.8 + 0.325	99.0 a	82.1 bcd	59.9 d-g	18.9 cd
15	simazine	1.8	94.0 b	32.9 i	7.5 mn	1.6 hi
16	simazine + oryzalin	1.8 + 1.6	99.0 a	69.2 e-h	23.9 jkl	3.9 f-i
17	simazine + thiazopyr	1.8 + 0.25	99.0 a	82.6 bcd	61.7 c-f	10.5 c-f
18	simazine + thiazopyr	1.8 + 0.325	99.0 a	75.2 c-g	55.2 e-h	10.5 c-f
19	thiazopyr	0.25	98.4 a	69.3 e-h	40.8 hij	6.8 e-h
20	thiazopyr	0.325	97.8 a	68.2 fgh	32.4 ijk	8.9 d-g
21	control	0.0	87.2 c	17.2 j	1.0 n	0.9 i

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.

Table A-10. Indiantown fourth weed control ratings, application date July 17, 1996.

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT
1	bromacil	2.128	99.0 a	97.8 a	92.0 ab	77.2 ab
2	diuron	2.128	99.0 a	92.4 bc	74.2 cde	62.4 bcd
3	bromacil + diuron	2.128 + 2.128	99.0 a	99.0 a	98.4 a	88.5 a
4	diuron + oryzalin	2.128 + 2.0	99.0 a	89.3 bc	71.3 cde	50.3 de
5	diuron + thiazopyr	2.128 + .375	98.4 ab	88.4 c	71.7 cde	62.4 bcd
6	diuron + thiazopyr	2.128 + .4875	99.0 a	86.5 cd	64.1 ef	56.6 cd
7	norflurazon	2.128	97.8 b	90.8 bc	84.7 bc	76.3 abc
8	diuron + norflurazon	2.128 + 2.128	99.0 a	98.4 a	96.3 a	89.3 a
9	norflurazon + simazine	2.128 + 2.637	99.0 a	99.0 a	94.1 ab	85.9 a
10	norflurazon + oxyfluorfen	2.128 + 1.2	99.0 a	99.0 a	96.0 a	88.5 a
11	oryzalin	2.0	96.3 c	60.2 f	34.3 g	25.2 gh
12	oxyfluorfen	1.2	99.0 a	85.0 cd	63.4 ef	48.8 def
13	oxyfluorfen + thiazopyr	1.2 + .375	99.0 a	91.4 bc	75.7 cde	56.9 bcd
14	oxyfluorfen + thiazopyr	1.2 + .4875	99.0 a	89.3 bc	75.5 cde	51.9 de
15	simazine	2.637	99.0 a	89.5 bc	70.7 cde	45.4 d-g
16	simazine + oryzalin	2.128 + 2.0	99.0 a	95.3 ab	81.9 bcd	62.5 bcd
17	simazine + thiazopyr	2.128 + .375	99.0 a	86.4 cd	66.5 def	57.1 bcd
18	simazine + thiazopyr	2.128 + .4875	99.0 a	77.1 de	47.9 fg	33.6 e-h
19	thiazopyr	0.375	98.4 ab	67.3 ef	39.7 g	26.5 gh
20	thiazopyr	0.4875	98.4 ab	72.0 ef	50.8 fg	24.2 h
21	control	0.0	94.0 d	68.5 ef	42.6 g	27.7 fgh

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.

Table A-11. Indiantown fifth weed control ratings, application date December 2, 1996.

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT
1	bromacil	2.128	99.0 a	99.0 a	96.9 a-d	92.2 a-d
2	diuron	2.128	99.0 a	99.0 a	91.7 efg	73.1 hij
3	bromacil + diuron	2.128 + 2.128	99.0 a	99.0 a	99.0 a	96.9 ab
4	diuron + oryzalin	2.128 + 2.0	99.0 a	98.4 ab	92.7 ef	82.9 e-h
5	diuron + thiazopyr	2.128 + .375	99.0 a	98.4 ab	85.9 ghi	73.7 g-j
6	diuron + thiazopyr	2.128 + .4875	99.0 a	99.0 a	95.3 b-f	86.2 c-f
7	norflurazon	2.128	99.0 a	97.8 b	96.0 b-e	91.4 b-e
8	diuron + norflurazon	2.128 + 2.128	99.0 a	99.0 a	99.0 a	96.9 ab
9	norflurazon + simazine	2.128 + 2.637	99.0 a	99.0 a	98.4 ab	97.8 a
10	norflurazon + oxyfluorfen	2.128 + 1.2	99.0 a	99.0 a	97.8 abc	93.7 abc
11	oryzalin	2.0	99.0 a	94.8 cd	83.5 i	61.2 j
12	oxyfluorfen	1.2	99.0 a	98.4 ab	92.2 ef	81.1 f-i
13	oxyfluorfen + thiazopyr	1.2 + .375	99.0 a	98.4 ab	93.7 def	83.2 e-h
14	oxyfluorfen + thiazopyr	1.2 + .4875	99.0 a	99.0 a	93.2 def	81.4 f-i
15	simazine	2.637	99.0 a	99.0 a	92.4 ef	68.6 j
16	simazine + oryzalin	2.128 + 2.0	99.0 a	99.0 a	94.1 c-f	87.5 c-f
17	simazine + thiazopyr	2.128 + .375	99.0 a	99.0 a	94.1 c-f	87.1 c-f
18	simazine + thiazopyr	2.128 + .4875	99.0 a	99.0 a	91.4 fgh	84.2 d-g
19	thiazopyr	0.375	99.0 a	93.2 d	85.3 hi	69.2 j
20	thiazopyr	0.4875	99.0 a	96.0 c	85.1 i	70.2 ij
21	control	0.0	99.0 a	92.9 d	81.9 i	43.3 k

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.

Table A-12. Indiantown sixth weed control ratings, application date March 24, 1997.

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT
1	bromacil	2.128	99.0 a	99.0 a	88.5 bc	74.0 bc
2	diuron	2.128	99.0 a	94.6 c-g	59.4 fg	39.0 d-h
3	bromacil + diuron	2.128 + 2.128	99.0 a	99.0 a	97.8 a	87.5 ab
4	diuron + oryzalin	2.128 + 2.0	99.0 a	94.4 c-g	73.4 de	53.1 d
5	diuron + thiazopyr	2.128 + .375	99.0 a	93.7 c-g	75.5 de	44.8 def
6	diuron + thiazopyr	2.128 + .4875	99.0 a	95.3 b-f	78.4 de	54.3 cd
7	norflurazon	2.128	99.0 a	95.6 b-e	89.2 bc	75.4 b
8	diuron + norflurazon	2.128 + 2.128	99.0 a	99.0 a	94.1 ab	91.4 a
9	norflurazon + simazine	2.128 + 2.637	99.0 a	98.4 ab	90.2 bc	85.2 ab
10	norflurazon + oxyfluorfen	2.128 + 1.2	99.0 a	97.8 abc	90.2 bc	83.9 ab
11	oryzalin	2.0	98.4 a	76.1 jk	38.8 i	23.8 g-j
12	oxyfluorfen	1.2	99.0 a	89.1 ghi	68.2 ef	31.8 e-i
13	oxyfluorfen + thiazopyr	1.2 + .375	99.0 a	92.7 d-h	76.1 de	51.7 de
14	oxyfluorfen + thiazopyr	1.2 + .4875	99.0 a	89.9 f-i	83.2 cd	48.1 def
15	simazine	2.637	99.0 a	83.8 ij	40.4 hi	21.2 hij
16	simazine + oryzalin	2.128 + 2.0	99.0 a	87.1 hi	51.9 gh	17.2 ij
17	simazine + thiazopyr	2.128 + .375	99.0 a	96.0 a-d	78.2 de	46.6 def
18	simazine + thiazopyr	2.128 + .4875	99.0 a	96.0 a-d	76.3 de	40.7 d-g
19	thiazopyr	0.375	99.0 a	91.4 d-h	68.4 ef	38.3 d-h
20	thiazopyr	0.4875	99.0 a	90.5 e-i	67.3 ef	30.9 f-i
21	control	0.0	98.3 a	73.0 k	34.2 i	13.0 j

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.

Table A-13. Arcadia first weed control ratings, application date June 1, 1995.

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT*
1	bromacil	1.6	91.4 a	74.4 abc	13.8 a	
2	diuron	1.6	84.6 abc	74.2 abc	13.7 a	
3	bromacil + diuron	1.6 + 1.6	88.5 ab	76.4 ab	10.7 abc	
4	diuron + oryzalin	1.6 + 1.6	72.5 c-f	47.7 e-h	6.9 a-d	
5	diuron + thiazopyr	1.6 + .25	79.3 b-e	46.8 fgh	7.3 a-d	
6	diuron + thiazopyr	1.6 + 0.325	80.3 a-d	51.0 d-h	3.9 bcd	
7	norflurazon	1.6	83.1 abc	57.1 c-g	6.3 a-d	
8	diuron + norflurazon	1.6 + 1.6	83.1 abc	67.5 a-e	12.5 ab	
9	norflurazon + simazine	1.6 + 1.8	81.1 abc	64.1 a-f	12.5 ab	
10	norflurazon + oxyfluorfen	1.6 + 0.8	82.2 abc	58.2 b-f	11.9 ab	
11	oryzalin	1.6	65.6 ef	37.0 ghi	8.4 abc	
12	oxyfluorfen	0.8	66.7 def	36.7 hi	3.4 cd	
13	oxyfluorfen + thiazopyr	0.8 + 0.25	66.7 ef	34.7 hi	3.4 cd	
14	oxyfluorfen + thiazopyr	0.8 + 0.325	65.6 ef	47.8 e-h	2.8 cd	
15	simazine	1.8	73.4 cde	48.6 e-h	1.6 d	
16	simazine + oryzalin	1.8 + 1.6	57.3 fg	35.3 hi	4.8 a-d	
17	simazine + thiazopyr	1.8 + 0.25	49.0 g	20.4 i	1.6 d	
18	simazine + thiazopyr	1.8 + 0.325	89.3 ab	77.3 a	8.3 abc	
19	thiazopyr	0.25	84.2 abc	60.1 a-f	8.9 abc	
20	thiazopyr	0.325	87.1 ab	70.3 a-d	10.7 abc	
21	control	0.0	57.1 fg	23.8 i	2.9 cd	

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.
* Rating at 120 DAT omitted due to poor weed control at 90 days.

Table A-14. Arcadia second weed control ratings, application date November 14, 1995.

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT
1	bromacil	1.6	98.4 a	93.2 a	89.1 a	77.3 a
2	diuron	1.6	97.0 ab	74.8 b	63.2 b	35.6 bc
3	bromacil + diuron	1.6 + 1.6	98.4 a	91.4 a	90.2 a	81.5 a
4	diuron + oryzalin	1.6 + 1.6	95.5 abc	66.2 bc	51.5 bc	24.7 c-f
5	diuron + thiazopyr	1.6 + .25	94.4 abc	55.2 cd	41.0 cde	13.5 efg
6	diuron + thiazopyr	1.6 + 0.325	95.3 abc	63.1 bcd	54.0 bc	21.4 c-g
7	norflurazon	1.6	95.3 abc	47.3 d	36.4 cde	11.1 fg
8	diuron + norflurazon	1.6 + 1.6	96.0 abc	65.1 bcd	50.0 bcd	20.8 c-g
9	norflurazon + simazine	1.6 + 1.8	96.0 abc	74.8 b	63.8 b	44.1 b
10	norflurazon + oxyfluorfen	1.6 + 0.8	93.2 bc	55.8 cd	39.6 cde	21.1 c-g
11	oryzalin	1.6	94.1 abc	46.9 d	32.4 de	10.1 gh
12	oxyfluorfen	0.8	95.0 abc	64.3 bcd	41.9 cde	15.1 efg
13	oxyfluorfen + thiazopyr	0.8 + 0.25	93.8 abc	62.2 bcd	46.4 b-e	18.7 d-g
14	oxyfluorfen + thiazopyr	0.8 + 0.325	94.4 abc	52.0 cd	37.7 cde	14.1 efg
15	simazine	1.8	93.2 bc	68.5 bc	51.0 bc	22.7 c-g
16	simazine + oryzalin	1.8 + 1.6	92.4 bc	66.4 bc	51.1 bc	26.1 cde
17	simazine + thiazopyr	1.8 + 0.25	93.2 bc	68.3 bc	53.1 bc	20.4 c-g
18	simazine + thiazopyr	1.8 + 0.325	96.3 abc	76.9 b	62.7 b	34.9 bcd
19	thiazopyr	0.25	90.3 cd	46.5 d	32.0 ef	10.8 fgh
20	thiazopyr	0.325	92.6 bc	47.3 d	31.2 ef	9.7 gh
21	control	0.0	82.8 d	27.9 e	16.9 f	2.2 h

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.

Table A-15. Arcadia third weed control ratings, application date April 16, 1996.

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT
1	bromacil	1.6	95.0 bc	82.2 b	41.2 bc	39.1 b
2	diuron	1.6	95.0 bc	74.1 bcd	22.6 def	17.8 def
3	bromacil + diuron	1.6 + 1.6	97.8 a	93.1 a	79.5 a	55.2 a
4	diuron + oryzalin	1.6 + 1.6	94.1 cd	67.6 c-g	19.9 def	13.0 efg
5	diuron + thiazopyr	1.6 + .25	95. 0 bc	71.1 b-f	25.5 c-f	18.8 cde
6	diuron + thiazopyr	1.6 + 0.325	95.0 bc	70.4 c-f	17.4 def	11.8 efg
7	norflurazon	1.6	95.0 bc	73.3 b-e	24.5 c-f	14.7 efg
8	diuron + norflurazon	1.6 + 1.6	95.0 bc	75.2 bcd	30.6 cde	17.4 def
9	norflurazon + simazine	1.6 + 1.8	95.0 bc	75.5 bcd	31.7 bcd	26.6 bcd
10	norflurazon + oxyfluorfen	1.6 + 0.8	95.0 bc	78.3 bc	49.6 b	30.6 bc
11	oryzalin	1.6	93.2 d	51.0 hi	11.2 fg	8.2 gh
12	oxyfluorfen	0.8	95.0 bc	45.6 ij	14.1 f	8.7 fgh
13	oxyfluorfen + thiazopyr	0.8 + 0.25	94.1 cd	61.4 e-h	18.5 def	12.4 efg
14	oxyfluorfen + thiazopyr	0.8 + 0.325	94.1 cd	64.5 d-g	17.7 def	12.4 efg
15	simazine	1.8	95.0 bc	34.7 j	3.0 gh	2.9 hi
16	simazine + oryzalin	1.8 + 1.6	96.0 b	60.3 fgh	15.1 ef	11.8 efg
17	simazine + thiazopyr	1.8 + 0.25	95.0 bc	56.1 ghi	12.4 fg	10.9 efg
18	simazine + thiazopyr	1.8 + 0.325	95.0 bc	70.2 c-f	17.4 def	11.5 efg
19	thiazopyr	0.25	95.0 bc	61.2 e-h	15.6 ef	11.5 efg
20	thiazopyr	0.325	95.0 bc	60.5 fgh	20.7 def	12.3 efg
21	control	0.0	79.0 e	11.9 k	1.0 h	1.6 i

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.

Table A-16. Arcadia fourth weed control ratings, application date September 5, 1996.

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT
1	bromacil	2.128	97.8 ab	77.6 abc	49.7 cde	26.5 bcd
2	diuron	2.128	94.1 cde	64.9 cd	28.8 fgh	15.5 def
3	bromacil + diuron	2.128 + 2.128	99.0 a	77.8 abc	56.4 cd	40.0 bc
4	diuron + oryzalin	2.128 + 2.0	94.1 cde	78.2 abc	41.4 def	23.4 cde
5	diuron + thiazopyr	2.128 + .375	92.4 def	70.3 a-d	31.9 efh	10.5 ef
6	diuron + thiazopyr	2.128 + .4875	93.2 c-f	71.2 a-d	28.9 fgh	8.7 f
7	norflurazon	2.128	93.2 c-f	73.2 a-d	62.2 bc	41.3 bc
8	diuron + norflurazon	2.128 + 2.128	96.0 bc	77.4 abc	67.6 abc	44.1 b
9	norflurazon + simazine	2.128 + 2.637	95.3 cd	81.3 ab	78.2 av	65.3 a
10	norflurazon + oxyfluorfen	2.128 + 1.2	96.0 bc	83.2 a	81.1 a	69.1 a
11	oryzalin	2.0	90.0 f	58.1 de	18.9 gh	8.8 f
12	oxyfluorfen	1.2	91.4 ef	60.7 de	49.0 cde	27.6 bcd
13	oxyfluorfen + thiazopyr	1.2 + .375	93.1 c-f	68.5 a-d	59.3 cd	44.8 b
14	oxyfluorfen + thiazopyr	1.2 + .4875	94.1 cde	72.2 a-d	57.2 cd	24.9 cde
15	simazine	2.637	92.2 def	45.1 ef	13.0 h	6.3 f
16	simazine + oryzalin	2.128 + 2.0	96.0 bc	58.1 de	17.6 gh	5.6 f
17	simazine + thiazopyr	2.128 + .375	94.1 cde	59.2 de	22.4 gh	6.8 f
18	simazine + thiazopyr	2.128 + .4875	94.1 cde	70.2 a-d	26.2 fgh	7.9 f
19	thiazopyr	0.375	91.1 ef	62.5 cde	34.6 efg	15.1 def
20	thiazopyr	0.4875	94.1 cde	66.4 bcd	24.1 fgh	8.6 f
21	control	0.0	61.1 g	35.7 f	19.2 gh	6.5 f

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.

Table A-17. Arcadia fifth weed control ratings, application date January 30, 1997.

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT
1	bromacil	2.128	99.0 a	91.4 cde	73.5 bcd	61.8 d-g
2	diuron	2.128	96.0 c	81.8 fg	43.3 f	39.9 h
3	bromacil + diuron	2.128 + 2.128	99.0 a	98.4 a	89.2 a	87.5 a
4	diuron + oryzalin	2.128 + 2.0	99.0 a	95.0 abc	78.5 a-d	75.7 a-d
5	diuron + thiazopyr	2.128 + .375	97.8 abc	91.7 cde	64.5 de	66.4 c-f
6	diuron + thiazopyr	2.128 + .4875	97.8 abc	90.2 cde	66.5 cde	65.1 c-g
7	norflurazon	2.128	99.0 a	95.0 abc	74.2 bcd	78.1 a-d
8	diuron + norflurazon	2.128 + 2.128	97.8 abc	94.6 a-d	77.6 a-d	79.5 abc
9	norflurazon + simazine	2.128 + 2.637	98.4 ab	96.9 ab	85.6 ab	83.2 ab
10	norflurazon + oxyfluorfen	2.128 + 1.2	97.8 abc	94.4 a-d	82.3 abc	82.9 ab
11	oryzalin	2.0	96.0 c	79.6 gh	52.0 ef	49.8 fgh
12	oxyfluorfen	1.2	97.8 abc	90.4 cde	52.1 ef	46.4 gh
13	oxyfluorfen + thiazopyr	1.2 + .375	96.2 c	88.5 def	63.1 de	51.9 e-h
14	oxyfluorfen + thiazopyr	1.2 + .4875	97.8 abc	92.0 b-e	70.3 cd	68.8 b-e
15	simazine	2.637	97.0 bc	71.3 h	13.4 g	13.4 i
16	simazine + oryzalin	2.128 + 2.0	96.3 c	86.8 efg	52.1 ef	49.3 fgh
17	simazine + thiazopyr	2.128 + .375	97.0 bc	91.0 cde	69.9 cd	70.9 bcd
18	simazine + thiazopyr	2.128 + .4875	97.8 abc	92.4 b-e	74.2 bcd	75.1 a-d
19	thiazopyr	0.375	97.8 abc	91.7 cde	71.6 bcd	61.4 d-g
20	thiazopyr	0.4875	97.8 abc	92.2 b-e	71.1 bcd	74.3 a-d
21	control	0.0	90.2 d	51.0 i	4.8 g	3.7 i

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.

Table A-18. Arcadia sixth weed control ratings, application date May 27, 1997.

Trt. #	Material	Rate Applied (lb ai/A)	Percent Weed Control			
			30 DAT	60 DAT	90 DAT	120 DAT
1	bromacil	2.128	99.0 a	94.1 ab	71.2 bc	61.1 c
2	diuron	2.128	99.0 a	69.2 def	20.8 def	15.2 def
3	bromacil + diuron	2.128 + 2.128	99.0 a	98.4 a	89.3 a	87.2 a
4	diuron + oryzalin	2.128 + 2.0	99.0 a	67.7 def	31.2 de	22.0 de
5	diuron + thiazopyr	2.128 + .375	99.0 a	65.3 ef	20.7 def	17.7 def
6	diuron + thiazopyr	2.128 + .4875	99.0 a	61.3 f	32.7 d	24.0 d
7	norflurazon	2.128	99.0 a	90.5 b	69.3 c	70.5 bc
8	diuron + norflurazon	2.128 + 2.128	99.0 a	93.2 b	78.6 abc	71.8 bc
9	norflurazon + simazine	2.128 + 2.637	99.0 a	96.0 ab	85.1 ab	83.2 ab
10	norflurazon + oxyfluorfen	2.128 + 1.2	99.0 a	96.0 ab	85.1 ab	80.3 ab
11	oryzalin	2.0	96.6 b	42.6 g	17.1 ef	13.3 def
12	oxyfluorfen	1.2	99.0 a	75.2 cde	17.1 ef	7.8 fg
13	oxyfluorfen + thiazopyr	1.2 + .375	99.0 a	74.9 cde	21.7 def	11.5 ef
14	oxyfluorfen + thiazopyr	1.2 + .4875	99.0 a	80.4 c	20.1 def	13.0 def
15	simazine	2.637	98.4 a	41.5 g	5.3 gh	3.0 g
16	simazine + oryzalin	2.128 + 2.0	98.4 a	63.1 f	14.9 fg	12.9 def
17	simazine + thiazopyr	2.128 + .375	99.0 a	76.3 cde	23.4 def	16.8 def
18	simazine + thiazopyr	2.128 + .4875	99.0 a	77.8 cd	32.3 d	24.7 d
19	thiazopyr	0.375	99.0 a	65.3 ef	20.7 def	15.8 def
20	thiazopyr	0.4875	99.0 a	73.2 c-f	26.3 def	19.6 de
21	control	0.0	79.3 c	11.8 h	1.6 h	1.6 g

Means followed by same letter within a column do not significantly differ (P=.05, Waller-Duncan).
Mean were transformed were and are reported in de-transformed data units.

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BIOGRAPHICAL SKETCH

Stephen Hubbard Futch was born in Dade City, Florida, on March 26, 1953. After graduating from Pasco Comprehensive High School in 1971, he enrolled at Central Florida Community College in Ocala and received an Associate of Arts degree in June 1973. He entered the University of Florida in September 1973 and received a Bachelor of Science in Agriculture degree in June 1975. He then managed Futch Grove Service, a citrus caretaking and harvesting business, in Dade City for ten years. In August of 1984 he entered the College of Business Administration at the University of South Florida to obtain a Master of Business Administration degree. Due to the severe freezes of 1993 and 1995 that destroyed much of the citrus in Pasco County, he accepted a position as County Extension Agent I with the Florida Cooperative Extension Service in Vero Beach in May 1985. While working toward the M.B.A., he remained employed with Futch Grove Service and then the Florida Cooperative Extension Service and completed the M.B.A. degree in May 1986. In 1990 he relocated to the Citrus Research and Education Center in Lake Alfred, Florida, and assumed the citrus programing activities for Hardee, DeSoto, Manatee, and Sarasota counties. In August 1994 he entered graduate school at the University of Florida to work on a doctoral program in horticultural science while remaining employed with the Florida Cooperative Extension Service. He expects to earn

his Ph. D. in December 1997. He and his wife Debbie have two children, William and David.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Megh Singh, Chair
Professor of Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Jeffrey G. Williamson, Cochair
Associate Professor of Horticultural Science

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Larry K. Jackson
Professor Emeritus of Horticultural Science

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Thomas A. Wheaton
Professor of Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Ashok K. Alva
Associate Professor of Soil and Water Science

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December 1997

Dean, College of Agriculture

Dean, Graduate School